# COMPUTER-AIDED DECISION ANALYSIS

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## *Theory and Applications*

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Dedicated to improving
the benefits of
computer-aided decision analysis

# Contents

# Introduction

The essence of decision-aiding software is that it consists of various forms of microcomputer programming designed to enable users to process a set of goals to be achieved, alternatives available for achieving them, and relations between goals and alternatives in order to choose the best alternative, combination, allocation, or predictive decision-rule.

Decision-aiding software should be distinguished from at least two other kinds of software that are relevant to making decisions but do not process goals, alternatives, and relations in order to arrive at prescriptive conclusions. One related type of software is information retrieval software. It can be very useful for determining such matters as the amount of money spent on a certain expense item in a certain year, the court cases that are relevant to a particular subject, or any kind of information that might be contained in a statistical almanac, encyclopedia, or other compendium of information. The second related type of software is office practice software, which can be useful for word processing reports, filing and retrieving in-house information, or doing bookkeeping relevant to financial matters. That kind of software is useful for organizing the decision-making processes of a government agency, a law firm, or any kind of office. Such software, however, does not process goals, alternatives, and relations to arrive at prescriptive conclusions.

Decision-aiding software can take a variety of forms. The most common might be the following:

1. Decision tree software for making decisions under conditions of risk, such as whether to go on strike or accept a management offer. A decision tree is usually pictured as looking like a tree on its side with branches and subbranches. The

branches generally represent alternative possibilities that depend on the occurrence or nonoccurrence of probabilistic events.

2. Linear programming software for allocating money, time, people, or other scarce resources to activities, places, tasks, or other objects to which the resources are to be allocated. In terms of form rather than function, linear programming involves maximizing or minimizing an objective function or algebraic equation subject to constraints generally in the form of inequalities like greater than or less than.
3. Statistical software for predicting how a future event is likely to occur, such as a trial, an election, or a weather occurrence, in the light of past events or expert opinions. Statistical software generally involves calculating averages or predictive equations in which decisions or other outcomes are related to factual inputs.
4. Spreadsheet-based software in which the alternatives tend to be in the rows, the criteria in the columns, relations in the cells, overall scores for each alternative in a column at the far right, and a capability for determining what it would take to bring a second-place or other-place alternative up to first place.
5. Rule-based software, which contains a set of rules for dealing with a narrow or broad field of decision making. The user gives the computer a set of facts, and the computer applies the rules to the facts in order to determine which alternative decision should be or is likely to be decided. Such software is sometimes referred to as artificial intelligence (AI) or expert systems, but the other forms of decision-aiding software also have characteristics associated with AI and expert systems.
6. Multicriteria decision-making (MCDM) software, which emphasizes multiple goals to be achieved, as contrasted to decision trees, linear programming, and statistical regression analysis, which emphasize a single objective function or a single dependent variable.
7. Decision-aiding software that focuses on a specific subject matter, as contrasted to the other software, which cuts across all subjects. Subject-specific software could relate to how to decide where to drill an oil well, how to deal with crisis situations in flying a plane, or any other specific decision-making situation.
8. Software that is useful for generating alternatives, goals, or relations but does not process those elements in order to draw a conclusion.

Decision-aiding software enhances various decision-making skills. These include:

1. Choosing among alternatives, where each alternative is a lump-sum choice, meaning that one cannot generally choose parts or multiples of such an alternative. The situation can involve mutually exclusive alternatives, or it can allow for combinations.
2. Allocating scarce resources such as money, time, or people to such objects as places or activities. The allocating can be with or without minimum or maximum constraints on how much each object can receive.
3. Explaining and predicting behavior, including individual cases or relations, in either the past or the future.
4. Teaching decision making, as well as actually making or prescribing decisions.

There are various obstacles to systematic decision making that decision-aiding software helps overcome. Those obstacles include:

1. Multiple dimensions on multiple goals. This is sometimes referred to as the apples and oranges problem, although the problem appears to become more difficult if the goals are more abstract, like freedom and equality. The measures may simultaneously involve hours, miles, dollars, 1–5 scales, pounds, pollution units, and other measures.
2. Multiple missing information. In its simplest form, this problem involves knowing the benefits and costs for a number of alternatives with the exception of one benefit or one cost. In its more challenging form, many benefits, costs, probabilities, and other inputs are unknown.
3. Multiple alternatives that are too many to analyze each one separately. This is especially the case in allocation problems. For example, there are at least 1,001 ways to allocate $1,000 between two budget categories A and B. One can give all $1,000 to A with $0 to B, $999 to A with $1 to B, and so on down to $0 to A with $1,000 to B.
4. Multiple and possibly conflicting constraints. In its simplest form, a number of constraints need to be met simultaneously, but they do not conflict. In its more challenging form, there may be minimum allocations required for each budget category, but the sum of the minimums adds to more than the maximum budget constraint.
5. The need for simplicity in drawing and presenting conclusions in spite of all that multiplicity. This is where spreadsheet-based software can be especially helpful because it can be relatively easy to manipulate and interpret in comparison to decision trees, payoff matrices, systems of simultaneous equations and inequalities, and arrow diagrams.

Other benefits from using decision-aiding software include:

1. Being more explicit about goals to be achieved, alternatives available for achieving them, and relations between goals and alternatives.
2. Being stimulated to think of more goals, alternatives, and relations than one would otherwise be likely to do.
3. Being able to handle multiple goals, alternatives, and relations without getting confused and without feeling the need to resort to a single composite goal or a single go/no-go alternative.
4. Being encouraged to experiment with changes in the inputs into one's thinking to see how conclusions are affected.
5. Being better able to achieve or more than achieve goals when choosing among alternatives or allocating scarce resources.
6. Being better able to predict future occurrences and explain past occurrences.
7. Being better able to teach decision making and other related skills to students in courses that involve controversial issues.

8. Being able more effectively to handle multidimensionality, missing information, and multiple constraints as surmountable obstacles to systematic decision making.
9. Being more able to deal with diverse subject matters as a result of having a cross-cutting decision analytic framework that is easy to use.
10. Becoming more capable of systematic decision analysis, even when the software is not available.

One of the most exciting developments regarding the future of decision-aiding software is the idea of being able to achieve superoptimum solutions, defined as those that are better than what each side in a controversy had originally proposed as its best alternative using each side's own goals and their relative weights. For example, the Republicans propose retaining the minimum wage at $3.35 in order to stimulate business. The Democrats propose raising the minimum wage to $4.00 in order to help labor. A superoptimum solution might be to allow business firms to pay as low as $3.00 an hour where they agree to hire the elderly, the handicapped, mothers of preschool children, or other unemployed people and also agree to provide on-the-job training. The workers, however, receive $4.50 an hour, with the government paying a $1.50 minimum wage supplement to the $3.00 business base. Business comes out ahead of its best expectations ($3.35) of being able to retain the existing minimum wage. Labor comes out ahead of its best expectation of getting $4.00 an hour. The taxpayer is better off if unemployed people are put to work who might otherwise be receiving public aid, food stamps, Medicaid, or public housing and maybe committing crimes. They can now become income-receiving taxpayers. This is a superoptimum solution; everybody comes out better off. It should be distinguished from a compromise solution, which would be between $3.35 and $4.00. Superoptimum solutions are facilitated by thinking in terms of multiple goals and alternatives using spreadsheet-based decision-aiding software.

For further information concerning decision-aiding software, see Patrick Humphreys and Ayleen Wisudha, *Methods and Tools for Structuring and Analyzing Decision Problems* (London: London School of Economics and Political Science, 1987); Saul Gass et al. (eds.), *Impacts of Microcomputers on Operations Research* (Amsterdam: North-Holland, 1986); and S. Nagel, *Decision-Aiding Software: Skills, Obstacles, and Applications* (London: Macmillan, 1990).

There are five parts to this book:

1. Part One provides a broad overview of decision-aiding packages, including criteria for evaluating them. It contains chapters by such prominent experts in the field as Bernd Rohrmann, Holger Schütz, Charles Vlek, Danielle Timmermans, Wilma Otten, and Ola Svenson.

2. Approaches that are based on management science and operations research. Chapter 4, by Ramesh Sharda, evaluates linear programming routines, and Chapter 5, by Jim McGovern, Danny Samson, and Andrew Wirth, builds on decision trees.
3. Spreadsheet-based software, with insightful analyses by Steven Sonka, Michael Hudson, and Ron Janssen.
4. Expert systems software, including rule-based and function-based expert systems, discussed by Paul J. Hoffman, and knowledge-based expert systems discussed by Marko Bohanec and Vladislav Rajkovič.
5. The book ends with two chapters describing general applications and increasing utilization of decision-aiding software by Floyd Lewis and Fred Wood.

The book thus provides broad coverage across a variety of methodological perspectives toward decision-aiding software. It also provides variety in disciplinary representation, including psychology, business administration, medicine, law, political science, economics, and engineering. The authors include both academics and practitioners from Australia, Germany, Scandinavia, the Middle East, India, Eastern Europe, the Netherlands, and the United States.

# Part One

# Comparing across Software Packages

This part provides an overview of a variety of decision-aiding software packages. One of its purposes is to present a typology for analyzing decision-aiding software. One set of classification categories is provided in the Contents of this book. The main categories there are (1) approaches based on management science and operations research, (2) spreadsheet-based software, and (3) expert systems software.

The second key purpose of this part is to develop a set of criteria for evaluating decision-aiding software packages. Some criteria might include the ability to deal in a meaningful way with such obstacles to systematic decision making as multiple dimensions on multiple goals; multiple missing information; multiple alternatives, especially in allocation problems; multiple and possibly conflicting constraints; and the need for simplicity in drawing and presenting conclusions in spite of all that multiplicity.

On the matter of multiple dimensions, that problem gets at the idea that the goals to be achieved in almost any decision-making problem are not so likely to be measured in the same way. For example, in the simplest of decision-making problems, there tend to be at least some goals that are desired benefits and some goals that are costs to be kept down. It is possible to have only one goal, such as maximizing profits or net benefits. Traditional management science or operations research usually works with only a single objective function. Where "one" goal is present, it is usually a composite of subgoals that have been aggregated, frequently by forcing a common measurement unit on all the goals, such as dollars or another monetary unit. In a typical public policy problem and in most nonbusiness problems, however, the benefits tend to be nonmonetary, and the costs are mainly monetary. This necessitates a method for determining how to subtract monetary costs from nonmonetary benefits in order to arrive at an overall score for each alternative.

On the matter of multiple missing information, that problem gets at the idea that complete facts and values tend to be missing from typical decision-making situations. One can arbitrarily exclude all goals or al-

ternatives for which there is a lack of information concerning relations between alternatives and goals or concerning the relative weights of the goals. Doing so, however, may mean only working with relatively unimportant goals and with alternatives that happen to be highly measurable or already measured. A good package is capable of dealing with problems in which the user does not know the benefits and/or costs for one or more alternatives on one or more goals.

"Multiple alternatives" refers to situations in which the alternatives may be too many to determine the effects of each one or even too many to determine how many there are. This is especially the case in allocation problems. If one merely wants to allocate $1,000 to two budget categories, there are 1,001 alternative ways of doing so without counting the pennies. One could give $1,000 to the first budget category and $0 to the second, $999 to the first and $1 to the second, and so on until one gives $0 to the first and $1,000 to the second. With $1,000,000 to allocate, there are 1,000,001 alternatives for only two budget categories. By adding more budget categories, the quantity of alternatives becomes astronomical. No formula has yet been developed to determine how many alternative ways one can allocate a budget of $B to a set of K budget categories, although we know that the alternatives increase greatly as $B and K increase. A good decision-aiding package can handle such important allocation decisions as well as decisions that involve choosing among two, three, or more discrete manageable alternatives.

Another criterion for judging decision-aiding software packages is how well they handle multiple constraints, including possibly conflicting constraints. The constraints could include minimum or maximum amounts, scores, or ratios for one or more goals or one or more alternatives. The constraints could also refer to restrictions on what constitutes an acceptable solution that are qualitative rather than quantitative. These constraints might be legal, political, psychological, conceptual, predictive, economic, administrative, constitutional, or something else. In a realistic decision-making problem, often there may be conflicting constraints, as in the common situation of having a minimum dollar need for food, shelter, and recreation, but the sum of those three minimums is more than the total budget available. A good package should be capable of handling such conflicting constraints in a meaningful way since good decision makers are capable of doing so without saying that problems containing conflicting constraints are unsolvable.

Another important criterion for decision-aiding packages is enabling the user to draw and present conclusions in a simple, user-friendly way. Some decision-aiding software requires a knowledge of complicated mathematics, statistics, algebra, logic, or other quantitative techniques, especially the software associated with management science and operations research. As a result, the software may be usable and understandable only by those with specialized training. What is especially frustrating is software that is both more complicated and less valid. That can frequently occur if the software requires highly precise data that are complicated to obtain or calculate. As a result, relevant variables may be

neglected whose absence makes the validity of the findings untrustworthy. Good software should provide simplicity without sacrificing validity, and it should especially not sacrifice both simplicity and validity for the sake of appearing sophisticated.

These are all general criteria; they are applicable regardless of the subject matter of the decision-aiding problem. We could develop more specific criteria for certain kinds of engineering, accounting, or legal problems. Management science/operations research software is especially applicable to industrial engineering problems. Spreadsheet software works well with accounting problems, and expert systems software may be especially relevant to legal problems. This book, however, is primarily concerned with decision analysis and decision-aiding software on a high level of generality. We thus tend to emphasize more general criteria. Not all of these criteria are emphasized in the chapters that follow, and some may be present implicitly rather than explicitly. Different people may consider some of these criteria more important than others. One important idea that this book seeks to communicate is that there are a variety of useful kinds of decision-aiding software, but beneath that variety there are underlying generalizations, including criteria for making systematic comparisons across software packages.

1

# The Evaluation of Decision Aids

Bernd Rohrmann and Holger Schütz

## INTRODUCTION: USES, USEFULNESS, AND USABILITY OF DECISION AIDS

This chapter deals with the following questions: How can the quality of tools for aiding human decision making be evaluated, what are the pertinent evaluation criteria and appropriate methodological approaches, and what is known so far from evaluative studies of decision aids? The various existing concepts, strategies, techniques, and programs claim to provide a sound theoretical basis and useful guidance for making rational decisions in the face of complex—usually multidimensional—choice problems. However, the critical question is whether such aims are actually achieved by employing decision-aiding technologies. To answer this question, evaluation research is needed. "Evaluation" means the scientific assessment of the content, processes, and outcomes of an intervention (measure, technology, program) and their appraisal according to defined criteria (goals, values). Only empirical investigation can clarify the usefulness and effectiveness of technologies.

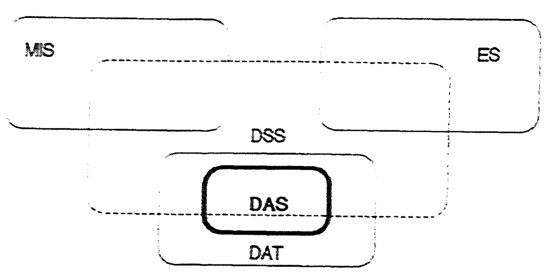
Before discussing the evaluation problem, the interesting types of decision-aiding technologies (DAT) will be specified. DAT refers to any explicit procedure for the generation, evaluation, and selection of alternatives (courses of actions, options) that is designed for practical application and multiple use (cf. Rohrmann 1986, p. 365). (For an overview see Humphreys & Wisudha 1987; Mitra 1986; Schütz & Jungermann 1988; and Vlek, Timmermans & Otten in this book.) Most DAT are based on decision theory as developed in economics, psychology, and, particularly, decision analysis (Bell, Raiffa & Tversky 1989; Edwards 1983; Keeney & Raiffa 1976; Keeney 1982; Von Winterfeldt & Edwards 1986).

Recently, a special kind of DAT has gained importance: computerized decision aids or decision-aiding systems. The rapid development of computer technology, providing increasingly more powerful and inexpensive computer systems, has made the computer an easily accessible tool for decision making as well.

There are various related computer-based tools (see Figure 1.1), including expert systems (ES), management information systems (MIS), and decision support systems (DSS), but they differ substantially in theoretical foundation and practical orientation. ES are usually linked to research on artificial intelligence. These systems consist of a knowledge base in which experts' knowledge about a specific area is stored and production rules, by which the system can draw inferences concerning a domain-specific problem. ES may thus support and advise a decision maker (Fox 1984; Hayes-Roth, Waterman & Lenat 1983; Lehner, Probus & Donnel 1985; Sutherland 1986). MIS are primarily designed to structure and present dispersed data in organizations so that the information is easily accessible and understandable to the decision maker (Keen & Scott-Morton 1978; Lee, McCosh & Migliarese 1988). In its narrow meaning, the notion of DSS is confined to assisting managers to analyze "unstructured" decision problems (Andriole 1989; Ford 1985; Minch & Sanders 1986). In a broader sense, it may serve as a generic term for all kinds of formalized aids for decision making (and thus includes ES as well as MIS) in quite disparate domains, such as industrial process control, military tactics, commercial management, or medical diagnosis (Sprague & Watson 1989; Zimolong & Rohrmann 1988); a further term, *decision support methods* (DSM), is used by Vlek, Timmermans & Otten (this book). A taxonomy of all kinds of DSS is offered by Zachary (1986). Altogether, there is no generally accepted terminology (Seilheimer 1988; Zimolong & Rohrmann (1988). Only DAT deal with "decisions" in a strict sense—that is, a deliberate choice between options according to evaluative criteria.

The following discussion concentrates on computerized DAT, decision-aiding systems (DAS) designed for personal computers and based explicitly on the decision-analytic approach. DAS have been designed for a multitude

**Figure 1.1**
**Decision-Aiding Technologies and Related Systems**



of purposes, including medical decision making, resource allocation, environmental conflict analysis, career counseling, and juridical and personal decision problems (for examples see Corner & Kirkwood 1991; Fraser & Hipel 1988; Jungermann 1980; Lehtinen & Smith 1985; Nagel 1988; Nagel & Mills 1991; Pauker & Kassirer 1981; Schütz & Jungermann 1988; Vlek & Cvetkovich 1989). Most DAS, however, are not domain specific but can be administered to all kinds of multiattribute decision problems by providing a formal structure or representation to formulate the problem (Pitz 1983; Wisudha 1985). Altogether at least fifty of such DAS appear to exist. Well-known programs include Arborist, Decaid, Decision Analyst, Decision Maker, Expert Choice, Hiview, MAUD, Lightyear, Prefcalc, P/G%, and Supertree. Most of them are for assessing values/utilities (decision making under certainty); a few handle uncertainty as well (decision making under risk). Usually they are designed as interactive stand-alone programs for application without further support from a decision analyst or counselor. Special applications for supporting group decision making also exist but will not be treated here (cf. Eden & Radford 1990; Kraemer & King 1988; Phillips 1990).

Three aspects of DAS can be differentiated: whether they are used (e.g., for what purposes, how often), whether they are useful (i.e., an effective tool), and whether they are usable under realistic conditions—or to put it in another way, usability determines to what extent the potential usefulness of a DAS can be exhausted. To be useful to a decision maker, a DAS must be applicable to her or his decision problem at hand. However, by using a DAS, the decision maker may be confronted with an additional problem: she or he has to interact with the computer (program). Thus, with regard to DAS, two problems can be distinguished (Streitz 1986):

1. The *content problem,* dealing with the decision problem at hand to which a particular analytic technique is applied.
2. The *interaction problem,* resulting from the fact that the decision maker makes use of an interactive computer program.

If one considers the primary reason for designing and applying DAS—to facilitate cognitively complex tasks—the importance of the interaction aspect or usability becomes evident: minimizing the interaction problem means to set free additional (cognitive) resources of the decision maker, which she or he can utilize for the analysis of the decision problem itself. Consequently the evaluation of DAS has to take both aspects into account.

Why is evaluation research important, and what can we learn from explicit evaluation studies that will not be learned from ordinary experience?

- Claims about the usefulness of DAS become provable in an objective and controllable manner.

- Coherent thinking about the purpose and the function of the employed tool is enforced, and the crucial attributes of DAS are identified.
- Empirical performance data can show whether the costs of a DAS (in terms of money or time or cognitive efforts) are justified.
- If several different DAS are available, a criterion-based choice between alternative programs is possible.
- The reasons that a DAS is effective or not can be explicated (because DAS are complex programs, the causes of success or failure are not self-evident).
- Careful evaluation provides the best basis for systematic improvement and further development of DAS.

Despite these arguments, relatively little systematic evaluation research on DAS has been done (Aldag & Power 1986; Rohrmann 1986). This holds even for DSS in general (Adelman 1991; Adelman, Rook & Lehner 1985; Andriole 1982; Benbasat & Nault 1990; Mahmood & Sniezek 1989; O'Keefe 1989; Riedel & Pitz 1986; Sainfort et al. 1990; Sharda, Barr & McDonnel 1988; Timmermans, Vlek & Hendrickx 1989).

In the following sections, first criteria for the usefulness and usability of DAS as well as methodological consequences for research designs will be discussed. Then some typical DAS evaluation studies will be reviewed. Finally, some perspectives on future tasks will complete this chapter.

## QUALITY CRITERIA FOR DECISION-AIDING TECHNOLOGIES

Defining evaluative criteria that are both relevant and measurable is the key problem for any evaluation study. The basic "goodness" criterion for technologies in general is effectiveness (Bunge 1967), defined as the degree to which an initial (unsatisfactory or not sufficiently satisfying) situation is changed toward a desired state, as defined by the (normative) goal for applying the technology—here, a DAT. This overall criterion has to be explicated and differentiated according to the specific problems and aims of users and the features of the employed tools.

Evaluation criteria have been treated with respect to DAT in general (Riedel 1986; Riedel & Pitz 1986, Rohrmann 1986; Zimolong & Rohrmann 1988), as well as confined to computerized DAS or DSS or ES (Adelman, Rook & Lehner 1985; Mahmood & Sniezek 1989; Rouse 1984; Sage 1981). Table 1.1 provides a summary of pertinent criteria, reflecting the different perspectives of authors, designers, and users (clients, counselors, etc.) of a decision aid.

### Decision-Analytic Quality

The ultimate goal of any decision maker is a good decision. However, this is a somewhat questionable criterion. As several authors have pointed out

**Table 1.1**
**Evaluation Criteria for Decision-Aiding Technologies**

| Evaluation aspect | Evaluation competence | | | |
|---|---|---|---|---|
| **Decision-analytic quality** | | | | |
| Theoretical/logical soundness | | | DT | |
| Ability to elicit goals and preferences | DM | DC | DT | |
| Utilization of information | | DC | DT | |
| Ability to reduce judgmental biases | | | DT | |
| Instructiveness of sensitivity analyses | DM | | | |
| Correctness of computations | | | DT | DS |
| Reliability of model results | | | DT | DS |
| Congruence between problem/generated model | DM | DC | | |
| Ex-post goodness of the decision | DM | | | |
| **Attitudinal effects** | | | | |
| Confidence in the approach | DM | | | |
| Acceptance of procedures | DM | DC | | |
| Reduction of decisional stress | DM | | | |
| Satisfaction with results | DM | DC | | |
| Frequency of application | DM | DC | | |
| **General and indirect benefits** | | | | |
| Problem clarification | DM | | | |
| Facilitation of communication | DM | DC | | |
| Improvement of decision skills | DM | DC | | |
| **User/system interaction** | | | | |
| Comprehensibility of tasks | DM | DC | | |
| Simplicity of handling | DM | | | DS |
| Software-ergonomic norms | DM | | | DS |
| Quality/clarity of information display | DM | | | DS |
| Visualization and graphical features | DM | | | DS |
| Transparency of program steps | DM | | | |
| Controllability of program course | DM | | DT | DS |
| Possibility of input changes | | | | DS |
| Explanatory power | DM | | DT | |
| Dependency on assistance | DM | DC | DT | DS |
| Quality of manual/handbook | DM | | DT | |
| **Flexibility** | | | | |
| Adaptability to tasks | DM | DC | DT | |
| Flexibility with input data | | | | DS |
| Adaptability to user's competence | | DC | DT | |
| Usability for group situations | | DC | | |
| **Economy/Efficacy** | | | | |
| Time requirements | DM | DC | | DS |
| Need for personnel | | DC | | DS |
| Training necessity | DM | DC | | |
| Monetary costs | DM | | | |
| Profit | DM | | | |

*Note:* DM = decision maker (the client, end user); DC = decision counselor (or analyst, mediator, etc.); DT = decision theorist (scientist, expert); DS = DAT software specialist.

(cf. Edwards et al. 1984), only the optimal usage of the information at hand in the decision situation should be evaluated, not the knowledge gained afterward. Furthermore, the actual outcomes of a decision might be determined by external (uncontrollable) influences rather than by the decision makers' behavior. Thus, the potential for a best possible decision should be increased by an aid, and decision aids should help to avoid decision traps (Russo & Shoemaker 1989; see also Vlek, Timmermans & Otten, in this book).

The criteria listed in the first section of Table 1.1 refer to the inherent characteristics of a DAS. The aid—the program and the rationale behind it—should be sound and correct in theoretical, logical, technical, and mathematical terms, and it should produce a valid representation of the user's intentions, knowledge, and preferences. The resulting evaluation/decision structure must reflect and possibly clarify the cognitive problem space of the decision maker.

Finally, analyzing the ex post goodness of DAS-generated decisions can be conclusive if the internal and external factors influencing the decision and its outcomes can be controlled.

### Attitudinal Effects

The attitudinal aspects listed in Table 1.1 are relevant under two perspectives. Only if the user has a positive attitude toward the DAS will she or he be ready to learn how to make the best use of the tool and to accept and apply the results. Decision making under conditions of complexity, high stakes, uncertainty, and time pressure is stressful (Janis & Mann 1977). Reducing this stress is useful (even if the decision quality is not improved). Moreover, the subjective overall evaluation and satisfaction with a DAS can be measured by the frequency of its (self-intended) use. From a marketing perspective, any data on a product's actual usage would be very informative.

### General and Indirect Effects

Users satisfied with a decision aid often refer to the "insights" they gained (rather than to specific formal results). Accordingly, cognitive changes associated with the decision analysis should be measured by psychometric means. Also, the better that decision makers understand their decision problem, the easier it is to communicate with other persons involved. This is important when several parties with conflicting objectives are concerned with a decision problem. Further, recommendations can be developed on the basis of a documentable decision analysis. Beyond analyzing and solving a particular decision problem, a DAS can increase general decision-making competence (transfer learning).

### User/System Interaction

The criteria discussed so far refer to the content problem of DAT evaluation. The fourth section of Table 1.1 deals with the interaction problem, an aspect that often seems to be underestimated.

While solving a decision task with a DAS, the decision maker has to "cooperate" with a computer program—instead of working just with paper and pencil or discussing the problem with a decision analyst or counselor. Generally, human-computer interaction has become an important issue as the number of users who are not trained in using computers increases. The central role of user-friendly computer systems has been recognized to be a major factor for their efficiency and acceptance (Monk 1984; Streitz 1986). This holds for DAS too, as several authors have noted (Bronner & De Hoog 1983; Von Winterfeldt & Edwards 1986; Riedel & Pitz 1986). "The challenge of developing an interactive decision-aiding system lies not so much in the design of algorithmic modules that form the basis of the system but more in the creation of a good interface between the user and the decision-analytic system. Computer technology must be challenged to its limits, while at the same time unnecessary complications must be avoided so as not to ignore the specifications for a 'user-oriented' system" (Wisudha 1985, p. 246).

Such requirements have been developed in human factors research and particularly in the new area of software ergonomics (Shneiderman 1987; Streitz 1986; cf. also DeMillo et al. 1987). From a cognitive point of view, Streitz (1986, p. 28) has defined user orientation as the cognitive compatibility of the user's relevant knowledge representation with the respective knowledge representation of the computer system. This view applies to the content problem as well as to the interaction problem. Successful interaction with the DAS requires the development and application of an adequate mental model. Further, the system should minimize the cognitive load by relieving the user's memory and facilitate the perception and processing of information. Pertinent criteria especially relevant for DAS evaluation have been included in Table 1.1.

DAS usability, however, is not just a software problem. If the instructions are hard to understand, if the various scaling tasks (e.g., weighting procedures) are difficult, or if the results are not sufficiently explained, a decision aid cannot be effective.

Finally, the characteristics of the user of the system have to be considered (Norman 1984). Obviously, evaluation criteria are different for an experienced professional decision analyst, a sophisticated computer owner, and an occasional DAS user.

### Flexibility

Most DAS are conceptualized as context-free tools, which, in principle, can deal with any particular decision problem. In reality, there are usually

many restrictions, depending on the characteristics of the decision task (alternatives, attributes, data type, etc.) and of the decision makers (laypeople versus experts, single versus group, etc.). Thus "adaptive" DAS (Rouse 1984) are needed, and flexibility becomes an important criterion.

### Economy/Efficacy

On the one hand, the implementation of DAS produces costs in terms of money, time, and personnel. If, on the other hand, decision-making performance is improved by using a DAS, costs should be reduced (or even profits increased).

The evaluation criteria discussed so far are neither exhaustive nor independent, and objective measurements may often be difficult. Therefore it is important to consider which information source is utilized in both empirical and theoretical/analytical evaluations. Those expected to have the best evaluative competence are noted on the right side of Table 1.1. Four groups are distinguished:

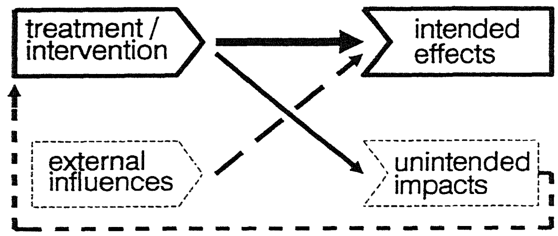
1. *Decision makers:* Only they (the end users) can describe their aims, problems, difficulties, and so on, and only they can finally evaluate whether the employed tools served as an aid and led to subjective satisfaction. Also, many criteria require an observation of the actual behavior of users.
2. *DAS experts:* Decision scientists will have the greatest competence in theoretical and methodological matters, and particularly the author/designer should know the intended function and the potential of the DAS best.
3. *Software specialists:* These experts are relevant for the evaluation of the programming and the user-system interfaces (including the information provided by screens and printers).
4. *Decision counselors:* Many DAS are employed by (or together with) a decision analyst who mediates between the client and the aiding system. (In some cases the counselor/analyst may be the virtual end user of the DAS.) Thus, these people have important insights into the usage of DAS, and they can judge whether the aims and needs of clients are actually met by the DAS.

Deliberations about evaluation criteria and evaluation sources will be a crucial part of designing an evaluation study. Not all criteria listed in Table 1.1 are relevant for every DAS. Instead, a critical selection of pertinent aspects, reflecting its specific purpose, is indicated.

## DIRECT AND INDIRECT CAUSES AND EFFECTS

The goal of an evaluation study is to assess whether implementation and use of a technology actually lead to the intended results. However, further causes and effects may occur (see Figure 1.2). The observed positive or negative outcomes of employing a DAS can be caused by external influences

**Figure 1.2**
**Evaluation: The Causation Problem**




rather than the features of the aid. Such external factors could be, for example, the knowledge of the decision maker, the behavior of the counselor, and the situational circumstances. Usually, interventions have not only desired results but also unintended impacts. Such side effects could be confusion or frustration of the decision maker and reduced self-confidence, or adverse consequences for the relatives of a client. In addition, experimental expectancy biases are to be considered, regarding the subjects as well as the researchers. Research on the social psychology of the experiment (Adair 1973; Rosenthal & Rosnow 1969) has identified a number of confounding effects:

- Subjects exposed to new working conditions respond positively when such changes are introduced as improvements, regardless of the particular function of the new conditions (so-called Hawthorne effect).
- Experimenters have particular expectations about the effects of their treatment, and they may, unintentionally, convey their hypotheses to their subjects (Rosenthal effect). In such a case the expectations may become self-fulfilling prophecies. This becomes relevant if the DAS author is the evaluator.
- Humans are likely to prefer information that supports existing beliefs: they overestimate the value of the information in favor of a considered alternative and disregard opposing data ("inertia" effect). In the case of decision aids, probably both parties (users and researchers) have positive prehypotheses on their effectiveness (as already induced by the label "aid").

Those biases may cause a spurious pseudo-effectiveness of the analyzed DAS.

In consequence, the whole picture has to be reflected in an evaluation approach, and appropriate designs are to be employed in order to clarify the causation structure.

## DESIGNING EVALUATION RESEARCH

When evaluating a DAT, two approaches are possible in principle: an analytical assessment by experts or an empirical study that collects data from users (cf. Figure 1.3). Because the field of evaluation research is highly de-

**Figure 1.3**
**Types of DAS Evaluation Studies**

- **Data collection**
  - analytical
  - empirical
    - cross-sectional
    - longitudinal
- **Focus**
  - content-oriented (substantive quality)
  - outcome-oriented (summative effectiveness)
  - process-oriented (formative/developmental view)
- **Information source**
  - user
    - decision maker
    - decision counselor
  - author
    - decision theorist
    - DAS program designer
- **Reference for comparisons**
  - unaided decisionmaking
  - counselor/decision analyst
  - other decision aids
  - normative target values

veloped (Cook, Leviton & Shadish 1985; Cronbach 1982; Herman, Morris & Fitz-Gibbon 1988; Patton 1986; Rossi & Freeman 1985; Shadish, Cook & Leviton 1991; Stufflebeam & Shinkfield 1985; Wortman 1983; Wottawa & Thurau 1990), a variety of concepts, methods, and designs is available in both cases. A further relevant area from which to develop research approaches is therapy outcome evaluation (Kendall & Norton-Ford 1982; Smith, Glass & Miller 1986; Wittmann & Matt 1990) because there are obvious similarities between (cognitive) psychotherapies and DATs (Fischhoff 1983; Jungermann 1980). An evaluation of technologies such as DAS can be based on three main perspectives:

1. *Content orientation:* The analysis deals with the substantive quality of the technology and its components (also called *input* or *system evaluation*).
2. *Outcome orientation:* The focus is on final results and consequences of applying a technology (also called *summative, impact,* or *product evaluation*).
3. *Process orientation:* All stages of the intervention and the development of effects are surveyed (also called *formative* or *descriptive evaluation*).

There are some basic methodological requirements (Adelman 1991; Riedel & Pitz 1986; Rohrmann 1986; Sage 1981):

- *Establishing criteria.* The particular goals to be achieved by the DAS have to be stated prior to its application, and the same criteria must be measurable before and after the intervention (the same is true if several aids are to be compared). Otherwise, the evaluation of eventual effects will be questionable or impossible.
- *Specification of target population.* Four kinds of subjects can be used as information sources: as "authors," either decision theorists or DAS program designers; and as "users," either decision counselors or clients (the final decision makers). The different expertise of these groups has already been discussed with respect to Table 1.1. To increase validity, all relevant groups should be included in an evaluation study. The same holds for different kinds of users (with respect to personal characteristics, substantive areas of decision making, social settings, etc.). In any case, the sampling decision will have critical influence on the result of the evaluation.
- *Study type.* Most powerful but also difficult to realize (and sometimes restricted in terms of external validity) are experimental approaches. A wide range of quasi-experimental designs are available as well and of particular importance for applied research. Often exploratory case studies are the most suitable means. A treatment of these issues is beyond the scope of this chapter (cf. Bromley 1986; Cook & Campbell 1979; Kerlinger 1986; Miller 1991; for a discussion focusing on decision support systems, see also Adelman 1991).
- *Timing of data collection.* Principally a pretest-posttest design is necessary for empirical evaluations. Especially in process evaluations, further test phases "in between," that is, a longitudinal design, will be indispensable. With respect to short-term versus long-term effects, also several points in time are needed. The timing of these phases can be crucial to distinguish between true effects and biases (e.g., overestimation and underestimation of the usefulness of the DAS because of time-dependent experiences). Furthermore, effects may change over time.
- *Inclusion of control groups.* The availability of control groups may be crucial for interpreting the results of a study and avoiding threats to validity, such as reactivity effects. Principal experimental controls refer to comparisons of groups with or without "treatment" and with or without pretest measurement. Yet the necessary randomization of subjects to conditions is often difficult or impossible; the same is true for placebo groups or comparable nontreatment groups. In this case quasi-experimental research designs (cf. Cook & Campbell 1979) are indicated.
- *Selection of decision problems.* The performance of a DAS can be tested only with respect to defined tasks. The sampling of those tasks should be representative in three senses: representative of the typical decision problems of clients, representative of their decision-making expertise, and representative of the features and capabilities of the DAS.
- *Observation of context effects.* Any application of a DAS occurs in a specific context determined by the characteristics of the user and the social situation, by the decision task and its relation to other problem areas, and so forth. Therefore, the implementation and the course of the DAS use as well as background events should be carefully monitored in order to identify relevant moderator effects.

- *Consideration of unintended outcomes.* The whole set of effects of employing a DAS should be considered in an evaluation study.

The design aspects strongly affect whether causal relationships can be established between the intervention (the DAS) and the outcomes that occur in the face of many confounding variables. Threats of internal and external validity necessitate systematic anticipation and prevention. (The most elaborated methodological position in this respect has been developed by the Campbell school). (For a thorough discussion related to evaluation research see Cook, Leviton & Shadish, 1985, or Lösel & Nowack, 1987.) Choosing an approach should be guided by the decision-making problem underlying the evaluation study (Adelman 1991). Often a combination of methods might be most appropriate.

The crucial stage of an evaluation study is the critical valuation of the observed effects. But what is the appropriate reference for comparisons? The outcomes of the DAS under study can be compared to:

- Normative target values, that is, performance standards defined by the designer of the DAS or by the user.
- Results of other decision aids (further DAS or similar DSS or ES) employed under the same conditions.
- Decision making aided by a counselor/analyst who conducts a formal decision analysis (or similar noncomputerized DAT).
- Unaided decision making, that is, a situation in which the decision maker deals with the task according to her or his own procedures.

These possibilities determine the necessary design of the investigation.

Finally, the evaluator should be independent: external evaluations will be more valid than those undertaken by the DAS authors themselves. In sum, overly simplistic approaches (or what Patton 1986 calls "quick and dirty evaluation") are not appropriate in the case of DAS evaluation; instead, advanced designs are required to overcome interpretative pitfalls and to gain reproducible, valid findings.

## KNOWLEDGE FROM EVALUATION STUDIES

After the discussion of substantive evaluation criteria and methodological issues, the question arises of what is known from actual evaluation studies about the uses, usefulness, and usability of DAS. The number of available evaluation studies is still small, and these studies are heterogeneous. Thus, a comparative review is difficult, and certainly the body of respective research does not enable a formal meta-analysis (Glass, McGaw & Smith 1981; Hunter, Schmidt & Jackson 1982; Hunter & Schmidt 1990). Instead, selected examples will be described and reviewed.

### Types of Evaluation

Two approaches outlined in Figure 1.3 are of particular interest: comparisons of DAS decision making with either unaided or human analyst supported decision making and comparisons among several DAS. While some empirical investigations have been carried out on the first issue, there are virtually no empirical studies addressing the second one. Most studies do not intend to evaluate a specific DAS but address the more general question of whether DAS in general improve human decision making.

In addition, a number of reviews have dealt with comparisons between DAS in an analytical way, providing an overview as well as a description of system features of available DAS, supplemented with a commentary on the strengths and weaknesses as judged by the authors (Henrion 1985; Radcliff 1986; Spezzano 1985; and Taylor & Taylor 1987). Although reviews cannot provide an objective test, they may be useful for potential DAS users: they usually provide knowledge concerning theoretical soundness, utilization of information, simplicity of handling, monetary costs, or the kind of decision problem the DAS can be applied to and how it performs compared to others. From an evaluation perspective, these issues correspond to the evaluation criteria outlined. Characteristics such as theoretical soundness or human engineering standards can very well be evaluated in an analytical fashion, without empirical investigation, and thus be treated accurately in a review. The major drawback is that the findings often depend on the particular set of DAS treated in the review. This does not matter in regard to issues such as theoretical soundness or monetary costs, but it may be of importance for criteria such as utilization of information or simplicity of handling, for which no objective or external scale of reference exists. Thus, to draw a general conclusion from this kind of DAS evaluation, one can say that DAS vary considerably in applicability, design, and sophistication of procedures, but one is still left with the question of their actual usefulness. Actual usefulness, of course, is an empirical question.

Most empirical evaluation studies are laboratory studies, limiting the ecological validity of their findings. However, investigations in real settings are extraordinarily difficult to carry out, since it is difficult to control all relevant factors. In the following, the knowledge from evaluation studies will be summarized by focusing on three aspects: (1) Are DAS actually used, for what purposes, and how often? (2) Are DAS useful (effective) tools? (3) Are DAS usable under realistic conditions?

### Are DAS Actually Used?

One salient operationalization of user acceptance and satisfaction is frequency of use. In practice, computerized decision aids are extensively applied in management and organizational settings (Elam, Huber & Hurt

1986). In many cases, however, these are not DAS in the sense outlined above—that is, based on decision analysis—but rather MIS types of tools.

A field for which several DAS have been designed is the area of career counseling. Here DAS are intended not only to support career decision making but more generally to improve the decision maker's vocational maturity (Katz & Shatkin 1983; Potocnic 1990). For example, the System of Interactive Guidance and Information (SIGI), designed by Katz and his associates, has been adopted at more than forty colleges and universities in the United States (Katz 1980). Wooler and his colleagues describe the development, testing, and use of various DAS supporting vocational decision making (Wooler 1982; Wooler & Lewis 1982; Wooler & Wisudha 1985). As an example, SELSTRA, a basically content-free DAS, has been specifically adapted to the field of career guidance by building in a core hierarchy of relevant attributes to stimulate the user's reasoning about personally important values. That approach focuses on helping the user to construct a complete and realistic attribute structure. However, reports about the actual employment of DAS in other areas are quite sparse. For example, Jungermann, Pfister and May (1991) have used MAUD4 for the purpose of research on decision making. Bronner and De Hoog (1984) also have used a (though completely revised) MAUD version to conduct experiments in this area. Nagel (1988) gives examples of how to apply the P/G% computer program (Nagel & Long 1985) to quite different decision problems, such as deciding whether to get married, choosing energy policies, and comparing alternative incentives for reducing pollution. The latest version of P/G% comes with about three hundred illustrative data files, showing the DAS's potential for a broad variety of applications. The actual number and typical fields of applications here remain unclear, and this holds for most other DAS too.

### Are DAS Useful?

Sharda, Barr and Mcdonnel (1988) reviewed empirical evaluation studies of DSS (including MIS) in organizational settings and found evidence for positive as well as negative effects of DSS on decision making. They conclude "that field and laboratory tests investigating superiority of DSS over non-DSS decisions show inconclusive results" (p. 144). It is not clear, however, whether this is due to methodological limitations of the studies reviewed or to the limited effectiveness of DSS. In their own empirical evaluation study, the effectiveness of decision-making groups (consisting of ninety-six senior-level undergraduate business students) who were either supported or not supported by a DAS in a financial decision-making game was compared. Sharda, Barr and Mcdonnel found DAS groups to make higher-quality decisions than non-DAS groups, as measured by the financial outcomes (net earnings) in the simulation. But on other quality measures, such as number of alternatives considered, time to reach a decision, and

confidence in the decision, no significant differences were found. Moreover, in the beginning of the simulation, DAS groups needed more time to reach decisions than did non-DAS groups, which may well be attributed to the time that subjects needed to become familiar with the DAS; later, decision times converged. The DAS used in the study was not a general decision-analytic one but rather a financial analysis tool that allows performance of what-if, goal-seeking, and Monte Carlo simulation analyses. Clearly, the findings are restricted to managerial or business decision making, since the subjects and decision problem as well as the DAS employed in the experiment are taken from this field.

Cairo (1983) gives an overview of a number of empirical evaluation studies on computer-assisted career counseling systems. He reports that the systems were judged by users as understandable, helpful in facilitating career development, and enjoyable. Nevertheless, he concludes that "we still know very little about the impact that computer-assisted counseling systems have on the career development of users" (p. 57). The author also found some evidence in the reviewed evaluation studies that the systems increase users' awareness of the need for planning, their concern with vocational choice, and their ability to relate information about themselves to potential occupations. Furthermore, evidence suggests that users learn more about career exploration resources, acquire relevant information, consider more alternatives, and increase the appropriateness of their occupational preferences. The main measure that has been applied in the studies reported by Cairo has been the effect of the particular career guidance system on various indexes of vocational maturity, as measured with tests such as the Career Development Inventory or Harren's Vocational Decision Making Checklist.

A number of laboratory studies have dealt with context-free DAS applied to personal decision problems, rooted in classical decision theory. In an experimental study, John, von Winterfeldt, and Edwards (1983) compared a conventional decision analysis performed by a human decision analyst with a decision analysis supported by MAUD3 (Multi-Attribute Utility Decomposition) (Humphreys & Wisudha 1979), a stand-alone DAS. First, thirty-five undergraduate college students with a decision problem currently important to them were identified and asked to generate at least four viable alternatives for their decision problem. The subjects were then divided into two experimental groups: the first group, consisting of twenty-four subjects, interacted with MAUD3 during a first session and with one of five human decision analysts during a second session (approximately one week later); the second group, consisting of the remaining eleven subjects, first interacted with a human analyst and then with MAUD3. Before and after each decision-analytic session, subjects were asked to give holistic ratings of the choice alternatives (they had generated before), to rank different vectors of alternative ratings, and to judge the usefulness of the technique (MAUD3 versus human analyst) they had employed. Then the two sets of attributes

each subject had generated in the MAUD3 and human analyst session were judged by three of the five human analysts with respect to completeness, logical as well as value independence, and overall quality of the attribute sets. Thus, a within-subject design was applied, allowing for comparisons of differences in (1) the individual preference order of alternatives resulting from each session; (2) the correspondence of the aided preference ordering with subjects' intuitive (holistic) judgments; (3) the number and quality of attributes generated by the subjects in each session; and (4) the subjects' satisfaction with the process and their confidence in the results. The authors found high convergence for (1) preference order of alternatives resulting from the MAUD3 and analyst session ($r = 0.63$), as well as for (2) aided preference ordering with subjects' intuitive judgments (ranging from $r = 0.50$ to $r = 0.88$). Further, (3) the number and quality of attributes generated was greater with the analyst, but the attribute sets generated with MAUD3 were judged to be more independent. Finally, (4) subjects' satisfaction with the analyst was higher than with MAUD3, while for subjects' confidence in the results, the reverse was true: MAUD3 attribute sets were judged to be more independent, both logically and value-wise. A final conclusion drawn by the authors on the usefulness of DAS is that "the computer sessions compared quite favorably with the analyst sessions" (p. 317) and that "stand-alone decision aids are feasible" (p. 318), though a number of problems (for example, the simplification of trade-off techniques or the inclusion of a problem-related database) remain to be solved. However, this study did not include a control group of unaided decision makers. Thus, no conclusions can be drawn about the principal benefit of systematic decision-aiding techniques.

Humphreys and McFadden (1980) conducted a study in which they intended to clarify the question of what and how a DAS can aid in the decision-making process. Provided with an (early) version of MAUD, four groups of subjects who were involved in decision-making problems in the arts and mass media first had to establish their preferences among the alternatives during an individual MAUD session. This was followed by an interview about the established preference orderings and the users' satisfaction with the process. Later, the individual judgments and preferences were discussed in the respective groups. Criticizing the convergent validation criterion as an invalid indicator for the degree to which a DAS actually aids, the authors used content analysis of the interviews and group discussions to discover those aspects in which MAUD aided the decision makers. The results indicate that decision makers, whose intuitive preferences did not agree with MAUD-generated preferences, found MAUD most useful. Reduction of goal confusion and increased consciousness about the structure of value-wise importances of attribute dimensions were the most important effects of decision making with MAUD. Again, in this study no control group was used to compare aided with unaided decision making. In addition, the num-

ber of subjects (altogether twenty-two) working on a particular decision problem was rather small (three, five, six, and eight in each group, respectively). This makes it difficult to assess the generalizability of the findings. Also, the duration of positive effects over time was not investigated.

Bronner and De Hoog (1983) addressed the question of how to improve the quality of DAS in order to facilitate intelligent and effective use of DAS for people without special training in decision analysis. A modified version of the MAUD2 computer program was used with forty subjects, who had to deal with two decision problems in sessions run individually. For all sessions, behavior observation data as well as protocols of the subject-program interaction were collected. Finally, subjects had to fill out a questionnaire concerning ease of use, perceived usefulness, and suggestions for improvement of the program. Most subjects judged the interaction with the DAS as "simple, clear and understandable" (p. 287) and found it particularly applicable to decision problems that were neither too trivial nor too emotionally important (e.g., choosing a job or an education). Similar to Humphreys and McFadden's (1980) findings, helping the decision maker clarify her or his decision problem turned out to be a major benefit. This study focuses on subjective measures such as subjects' judgments of DAS applicability and usability. The question of whether the use of computerized decision aids actually increases decision quality is not addressed.

Timmermans, Vlek, and Hendrickx (1989; cf. also Timmermans 1991) in an experimental study compared the effectiveness of decision making under three conditions: subjects were supported by a trained counselor or by a DAS or were not supported at all. The authors used two kinds of measures for effectiveness. Objective measures included time needed for analyzing the decision problem, number of attributes generated, and convergence of intuitive preferences and preferences generated during the aided decision process. Subjective measures were user satisfaction with both procedure and resulting choice, experienced difficulty of the procedure, and acceptance of the decision-analytic method. In general, the results of the study support the claim of DAS usefulness. Though both counselor- and computer-supported decision making seems to be less useful than unaided decision making with regard to the time needed, more attributes were considered in the supported decision-making conditions, indicating a more thorough decision process. Moreover, subjects judged the decision-aiding procedures as especially useful for structuring and understanding the problem at hand. No significant differences were found between the computer-supported and the counselor-supported conditions. Compared with the unaided condition, subjects in the two support conditions were less satisfied with the decision process; no differences between the three conditions were found for the final choice. Finally, and perhaps most important, the experienced difficulty of the decision problem turned out to be quite important for the effects of the decision-aiding procedures. When the decision problem was regarded as diffi-

cult, decision support was more effective (more often led to a change in the final preference) than when it was regarded as simple. This indicates that DAS might be particularly useful for complex decision problems and that under these conditions decision makers are willing to rely on DAS support. In sum, although this study might be somewhat restricted in the subjective relevance of the decision problems treated, the comprehensive experimental approach allows for instructive and valid conclusions about the usefulness of DAS.

While these experiments dealt with personal decision problems, further studies have addressed other aspects. Goslar, Green, and Hughes (1986), using an ill-structured business decision problem, investigated the effects of three factors: DAS availability, DAS training, and high and low data availability on several measures of decision-making performance. Their dependent variables included the number of alternatives considered, the amount of time needed and the amount of data considered for decision making, confidence in the decision, each subject's decision processing, and overall performance. No main effect was found on any of the dependent variables. However, significant interaction effects were found with regard to the number of alternatives considered: subjects with DAS training, DAS availability, or high amount of data available considered fewer alternatives. The authors conclude that neither DAS availability nor DAS training enhances decision-making performance, and they make the important point that more knowledge on the logic of decision making itself may be required. In this experiment, however, subjects in the DAS availability condition interacted with the DAS through trained intermediaries rather than directly. This was done in order to exclude biases resulting from subjects' potential previous computer experience. Although this measure indicates careful experiment planning, at the same time it poses a problem for the interpretation of the findings, since it remains unclear whether the failure to obtain significant effects is due to the fact that DAS availability was indirect and that DAS training was purely theoretical. In addition, interacting with a DAS via intermediaries certainly is unrealistic for typical DAS usage. Finally, the decision aid studied was a financial analysis program and not based on the decision-analytic approach.

In a similar context, Aldag and Power (1986) compared students' computer-aided decision making with unaided decision-making performance (both judged by independent raters) in an experimental between-subjects design. The authors further examined the students' attitudes toward the DAS, as well as their perceptions of their decision making and performance. Overall, attitudes toward the DAS were favorable, and limited support was received for the hypothesis that DAS users would "exhibit more confidence in, and satisfaction with, their decision processes and recommendations" (p. 576) than would non-DAS users. However DAS users were not rated to be superior to non-DAS users by the independent raters. The authors' con-

clusion is that DAS "seem to have a high face validity and may result in positive user affect and enhanced confidence. To this date, however, claims of improved decision quality must be taken primarily on faith" (p. 586). The authors dealt with a rather specific set of evaluation criteria; a distinctive feature of the study is to employ independent raters for assessing decision quality. Similar results—questioning the efficiency of DSS—have been reported by, for example, Pots, Van Schaik, and Sol (1989) and Van Schaik and Sol (1990).

### Are DAS Usable under Realistic Conditions?

When DAS are implemented within an institutional context, DAS seem to be quite usable. This is the case, for example, with many computerized career decision aids and with most DSS, where technical working ability as well as procedural advice for the user are provided. But what about the individual decision maker who has neither technical nor procedural advice at hand? Several studies already cited point to potential obstacles for real-life usability in this case. According to the distinction made in the introduction, two types of problems are to be distinguished: content problems and interaction problems.

Although the second aspect—the criteria addressed in Table 1.1—has not been investigated systematically in any of the reviewed studies, several authors emphasize its importance for the real-life application of DAS (Bronner & De Hoog 1983; Sharda et al. 1988). Yet in the light of cited reviews (Radcliff 1986) it becomes clear that not all DAS are sufficient for standards of "professional" software (e.g., word processors, database systems). However, usability—and probably even more user acceptance—of DAS depends not only on the soundness and theoretical quality of the decision-analytic rationale and its transformation into a DAS but on the user friendliness of DAS as well.

With the content problem, two aspects may be distinguished, one concerning the applicability of DAS to real-life decision problems, the other dealing with the problem of understanding and managing the procedures and tasks required by the DAS. The latter issue has been addressed in several evaluation studies. Sharda, Barr, and Mcdonnel (1988) mention the amount of time their subjects needed to learn how to use the DAS. In general, however, the effort required to master a DAS has been neglected in DAS evaluation studies (although this does not generally hold for DAS evaluation in a business context, where "time is money"). In DAS-supported decision making, the following procedures appear to be particularly critical: the structuring of the decision problem (elicitation of attributes and alternatives) and the elicitation of attribute weights. Most DAS do not support decision problem structuring, although several authors have stressed the crucial meaning of this phase (von Winterfeldt 1980); an exception is, for example, GHOST

(Landvogt, Pfister & Jungermann 1989). The attribute elicitation technique implemented in MAUD obviously poses problems for many users, as both Bronner and De Hoog (1983) and John, von Winterfeldt, and Edwards (1983) report. Moreover, these authors report about subjects' problems with understanding and performing the MAUD attribute weight elicitation procedure, the so-called basic reference lottery tickets technique. However, recent versions of MAUD (Decision Analysis Unit 1986) employ a different and simpler weight elicitation technique, called the compensation method. In view of these problems, it seems quite questionable whether an inexperienced decision maker actually can stand alone with a so-called stand-alone DAS. This critique, of course, is by no means limited to MAUD. On the contrary, DAS that do not support these critical decision-making stages at all are probably less usable (and useful) for a naive user. The cited findings of Goslar, Green, and Hughes (1986), where DAS availability had little effect on decision making for an ill-structured decision problem, support this conjecture.

The applicability of DAS to real-life decisions points to a basic problem and applies to decision analysis in general as well. The question is whether those aspects of decision making typically supported by DAS are actually those for which people feel they need help most. This is particularly true for decision problems that do not easily fit into the predetermined decision-analytic problem structure, as this is the case with many personal decision problems (cf. Jungermann 1980; Jungermann & Schütz 1992; Pitz 1987). Virtually no studies address the question of whether a real-life decision maker with a "real" decision problem would actually use a DAS, even if she or he had a personal computer with an appropriate DAS at hand. Subjects of the Bronner and De Hoog (1983) study have indicated the type of decision problems for which they feel computerized decision aids would be appropriate: decision problems at an intermediary level. But what about decision problems where the decision maker is involved in a highly emotional manner, as in genetic counseling? Pitz (1987) has given a thorough analysis of the difficulties of applying (noncomputerized) decision aids to this problem, but he also recognizes their potential benefits. Empirical evidence, however, is still missing.

Taken together, only a limited number of the evaluation criteria have actually been used in the evaluation studies reviewed here. Typically, measures of decision-analytic quality, such as utilization of information, or attitudinal effects, such as satisfaction with results or confidence in the approach, are investigated, but not as completely as suggested in the theoretical literature. Other evaluation criteria, such as measures of user/system interaction or of flexibility, have barely been taken into account. Furthermore, the development or change of DAS effects and the stability of outcomes over time have been virtually ignored. In addition, methodological prerequisites for valid evaluations are partly missing. For example, not all evaluation studies in-

clude control groups. All in all, no consistent picture emerges from the substantial findings. While applications of DAS generally seem to produce positive attitudinal effects, as yet little is known about the specific conditions under which DAS substantially support human decision making.

## CONCLUSIONS: PERSPECTIVES FOR FUTURE RESEARCH

Does the available research on DAS evaluation answer the raised substantive questions on uses, usefulness, and usability of these tools, and are the discussed methodological requirements fulfilled? Obviously, this has been only partly achieved. In our view, both enlarged and improved evaluation is indicated:

- The body of DAS evaluation studies is too small in quantitative and qualitative terms. For many DAS, there is no evaluative knowledge at all (only MAUD received larger interest). Also, very few evaluation results have been replicated by other researchers. Thus, the validity of findings is restricted.
- There is a particular need for experimental studies in which the behavior of subjects is investigated by observation methods. However, such studies would reveal little unless strict design criteria were met.
- The types and characteristics of decision-making problems for which each DAS has been evaluated are limited, and the same holds for user characteristics. However, it is a well-established finding from research on behavioral decision making that the decision-making context is crucial for the decision process, as well as for decision outcomes. Thus, for many DAS, it is not clear for which kind of decision problems and for which type of decision makers they are appropriate or unsuited (see Svenson 1990, or Vlek, Timmermans & Otten, this book, for a taxonomy of decision problems). Further, the required competence level should be clarified. A comprehensive evaluation would include both novice and experienced decision makers and vary the complexity of tasks to be treated by the DAS.
- A related approach would be to investigate the specific problems of users and to perform a kind of user needs analysis. The results could be related to tool-oriented evaluations.
- Another question is whether findings can be generalized across societal groups or even cultures. Actually some authors stress that decision behavior is culture specific (Bontempo 1990; Hofstede 1980) and deeply rooted in the philosophical tradition of a culture. Cross-cultural research on decision making (see McDaniels & Gregory 1991 for an agenda) might clarify this aspect of external validity.
- There is virtually no empirical knowledge concerning the relative usefulness of different DAS compared with each other. Of course, this knowledge would be quite valuable for potential DAS users, since the problem of choosing an appropriate decision aid can be a decision problem as well. Analytical knowledge, as provided by DAS reviews, is helpful but not sufficient. More comparative data of DAS performance with respect to defined types of decision tasks could aid this meta decision problem. Incidentally, decision analysis is an excellent tool for evaluation

research (see Pitz & McKillip 1984). Thus, a DAS evaluation could easily be conducted via a DAS.

- For many years the extent to which the (considerable) complexity and difficulty of decision-aiding technologies can be reduced without loss in precision and validity has been discussed. In this context, variants of DAS could be examined in systematic experiments in order to analyze whether the same effectiveness and usefulness is achievable with simpler procedures and less effort.

This list of considerations and requests might sound somewhat theoretical or even naive. We know that proper studies in realistic settings are quite an effort and that usually not all reasonable goals and requirements can be achieved in a single study. Even worse, there might not be a great interest in DAS evaluation at all (perhaps outcomes would be discouraging?). Nevertheless, if the aim is to aid rational decisions about decision aids, more evaluation is indeed needed. It should be done by independent (external) evaluators and in a utilization-oriented way; ignored evaluations are useless.

## REFERENCES

Adair, J. G. (1973). *The human subject—The social psychology of the psychological experiment.* Boston: Little, Brown.

Adelman, L. (1991). Experiments, quasi-experiments, and case studies: A review of empirical methods for evaluating decision support systems. *IEEE Transactions on Systems, Man, and Cybernetics, 21,* 293–301.

Adelman, L., F. W. Rook, and P. E. Lehner. (1985). User and R&D specialist evaluation of decision support systems. *IEEE Transactions on Systems, Man, and Cybernetics, SMC-15,* 334–342.

Aldag, R. J., and D. J. Power. (1986). An empirical assessment of computer-assisted decision analysis. *Decision Science, 17,* 572–588.

Andriole, S. J. (1982). The design of microcomputer-based personal decision-aiding systems. *IEEE Transactions on Systems, Man, and Cybernetics, 12,* 463–469.

———. (1989). *Handbook of decision support systems.* Blue Ridge, PA: TAB.

Bell, D. E., H. Raiffa, and A. Tversky. (eds.) (1989). *Decision making: Descriptive, normative and prescriptive interactions.* Cambridge: University Press.

Benbaset, I., and B. R. Nault. (1990). An evaluation of empirical research in managerial support systems. *Decision Support Systems, 6,* 203–226.

Bontempo, R. (1990). Cultural differences in decision making. In W. H. Locke (ed.), *Judgment and decision making.* Singapore: Time.

Bromley, D. B. (1986). *The case-study method in psychotherapy and related disciplines.* New York: Wiley.

Bronner, F., and R. de Hoog. (1983). Non-expert use of a computerized decision aid. In P. Humphreys, O. Sevenson and A. Vari (eds.), *Analyzing and aiding decision processes* (pp. 281–299). Amsterdam: North-Holland.

———. (1984). The intertwining of information search and decision aiding. *Acta Psychologica, 56,* 125–139.

Bunge, M. (1967). *Scientific research.* Berlin: Springer.

Cairo, P. C. (1983). Evaluating the effects of computer-assisted counseling systems. *Counseling Psychologist, 11,* 55–59.

Cats-Baril, W. L., and G. P. Huber. (1987). Decision support systems for ill-structured problems: An empirical study. *Decision Science, 18,* 350–372.

Cook, T. D., and D. T. Campbell. (1979). *Quasi-experimentation: Design and analysis issues for field settings.* Chicago: Rand McNally.

Cook, T. D., L. C. Leviton, and W. J. Shadish, Jr. (1985). Program evaluation. In G. Lindzey and E. Aronson (eds.), *The handbook of social psychology* (pp. 699–720). London: Random House.

Corner, J. L., and C. W. Kirkwood. (1991). Decision analysis applications in the operations research literature, 1970–1989. *Operations Research, 39,* 206–219.

Cronbach, L. (1982). *Designing evaluations of educational and social programs.* San Francisco: Jossey-Bass.

Decision Analysis Unit (ed.) (1986). *MAUD6 user manual.* London: London School of Economics and Political Science.

DeMillo, R. A., R. J. McCracken, R. J. Martin, and J. F. Passafiume. (1987). *Software testing and evaluation.* Menlo Park: Benjamin/Cummings.

Eden, C., and J. Radford. (eds.) (1990). *Tackling strategic problems. The role of group decision support.* London: Sage.

Edwards, W. (1983). Decision analysis—A non-psychological psychotechnology. In V. Sarris and A. Parducci (eds.), *Perspectives in psychological experimentation—Towards the year 2000* (pp. 341–351). London: Erlbaum.

Edwards, W., J. Kiss, G. Majone, M. Toda, and C. Vlek. (1984). What constitutes "a good decision"? *Acta Psychologica, 56,* 5–27.

Elam, J. J., G. P. Huber, and M. E. Hurt. (1986). An examination of the DSS literature (1975–1985). In E. R. McLean and H. G. Sol (eds.), *Decision support systems: A decade in perspective* (pp. 1–17). New York: Elsevier.

Fischhoff, B. (1983). Decision analysis: Clinical art or clinical science? In L. Sjöberg, T. Tyska, and J. A. Wise (eds.), *Decision analysis and decision processes* (pp. 68–94). Lund: Doxa.

Ford, F. N. (1985). Decision support systems and expert systems: A comparison. *Information and Management, 8,* 21–26.

Fox, J. (1984). Formal and knowledge-based methods in decision technology. *Acta Psychologica, 56,* 303–331.

Fraser, N. M., and K. W. Hipel. (1988). Using the DecisionMaker computer program for analyzing environmental conflicts. *Journal of Environmental Management, 27,* 213–228.

Glass, G. V., B. McGaw, and M. L. Smith. (1981). *Meta-analysis in social research.* Beverly Hills: Sage.

Goslar, M. D., G. I. Green, and T. H. Hughes. (1986). Decision support systems. An empirical assessment for decision making. *Decision Science, 17,* 79–91.

Hayes-Roth, F., D. A. Waterman, and D. B. Lenat. (eds.) (1983). *Building expert systems.* Reading, MA: Addison-Wesley.

Henrion, M. (1985). Software for decision analysis: A review of RISKCALC, ARBORIST and SUPERTREE. *OR/MS Today, 12/5,* 24–29.

Herman, J. L., L. L. Morris, and C. T. Fitz-Gibbon. (1988). *Evaluator's handbook.* London: Sage.

Hofstede, G. (1980). *Cultural consequences—International differences in work related values.* Beverly Hills: Sage.

Humphreys, P., and W. McFadden. (1980). Experiences with MAUD: Aiding decision structuring versus bootstrapping the decision maker. *Acta Psychologica, 45,* 51–69.

Humphreys, P., and A. Wisudha. (1979). *Multi-attribute utility decomposition MAUD.* Technical Report 79-2/2. London: Decision Analysis Unit, Brunel University.

———. (1987). *Methods and tools for structuring and analysing decision problems—A catalogue and review.* Technical Report 87-1. London: Decision Analysis Unit, London School of Economics and Political Science.

Hunter, J. E., and F. L. Schmidt. (1990). *Methods of meta-analysis. Correcting error and bias in research findings.* Beverly Hills: Sage.

Hunter, J. E., F. L. Schmidt, and G. B. Jackson. (1982). *Meta-analysis. Cumulating research finding across studies.* Beverly Hills: Sage.

Janis, I. L., and L. Mann. (1977). *Decision making: A psychological analysis of conflict, choice, and commitment.* New York: Free Press.

John, R. J., D. von Winterfeldt, and W. Edwards. (1983). The quality and user acceptance of multiattribute utility analysis performed by computer and analyst. In P. Humphreys, D. Svenson and A. Vari (eds.), *Analyzing and aiding decision processes* (pp. 301–319). Amsterdam: North-Holland.

Jungermann, H. (1980). Speculations about decision-theoretic aids for personal decision making. *Acta Psychologica, 45,* 7–34.

Jungermann, H., H.-R. Pfister, and R. S. May. (1991). Competing motivations or changing choices: Conjectures and some data on choice-action consistency. In J. Kuhl and J. Beckmann (eds.), *Volition and personality.* Göttingen: Hogrefe.

Jungermann, H., and H. Schütz. (1992). Personal decision counseling: counselors without clients? *Applied Psychology: An International Review, 41,* 185–200.

Katz, M. R. (1980). SIGI: An interactive career decision making. *Journal of College Student Personnel, 21,* 34–40.

Katz, M. R., and L. Shatkin. (1983). Characteristics of computer-assisted guidance. *Counseling Psychologist, 11,* 15–31.

Keen, P. G. W., and M. S. Scott-Morton. (1978). *Decision support systems: An organizational perspective.* Reading, MA: Addison-Wesley.

Keeney, R. L. (1982). Decision analysis: An overview. *Operations Research, 30,* 803–838.

Keeney, R. L., and H. Raiffa. (1976). *Decisions with multiple objectives: Preferences and value tradeoffs.* New York: Wiley.

Kendall, P. C., and J. D. Norton-Ford. (1982). Therapy outcome research methods. In P. C. Kendall and J. N. Butcher (eds.), *Handbook of research methods in clinical psychology* (pp. 429–461). New York: Wiley.

Kerlinger, F. N. (1986). *Foundations of behavioral research.* New York: HRW.

Kraemer, K. L, and J. L. King. (1988). Computer-based systems for cooperative work and group decision making. *ACM Computer Surveys, 20,* 115–146.

Landvogt, W., R. Pfister, and H. Jungermann. (1989). *GHOST: Ein Computerprogramm zur Strukturierung von Zielen.* Berlin: Gemeinschaft für Entscheidungs- und Risikoanalyse.

Lee, R. M., A. M. McCosh, and P. Migliarese. (1988). *Organizational decision support systems.* Amsterdam: North-Holland.

Lehner, P. E., M. A. Probus, and M. L. Donnel. (1985). Building decision aids: Exploiting the synergy between decision analysis and artificial intelligence. *IEEE Transactions on Systems, Man and Cybernetics, 15,* 469–474.

Lehtinen, M. W., and G. W. Smith. (1985). The personal computer as marriage counselor. Special Issue: Personal computers and the family. *Marriage and Family Review, 8,* 137–154.

Lewis, F. Decision-aiding software for group decision making. This book.

Lösel, F., and W. Nowack. (1987). Evaluationsforschung. In J. Schultz-Gambard (ed.), *Angewandte Sozialpsychologie* (pp. 57–87). Munich: Psychologie Verlags Union.

McDaniels, T. L., and R. S. Gregory. (1991). A framework for structuring cross-cultural research in risk and decision making. *Journal of Cross-Cultural Psychology, 22,* 103–128.

Mahmood, M. A., and J. A. Sniezek. (1989). Defining decision support systems: An empirical assessment of end-user satisfaction. *INFOR, 27,* 253–271.

Miller, D. C. (1991). *Handbook of research design and social measurement.* London: Sage.

Minch, R. P., and G. L. Sanders. (1986). Computerized information systems supporting multicriteria decision making. *Decision Sciences, 17,* 395–413.

Mitra, G. (ed.) (1986). *Computer assisted decision making.* Amsterdam: North-Holland.

Monk, A. (1984). *Fundamentals of human-computer interaction.* London: Academic Press.

Nagel, S. (1988). Decision-aiding software for all fields of knowledge. *International Journal of Information Management, 8,* 123–140.

Nagel, S., and J. Long. (1985). *The P/G% program manual.* Urbana: University of Illinois.

Nagel, S., and M. K. Mills. (1991). Decision-aiding software and the law. *Interfaces, 21,* 65–75.

Norman, D. A. (1984). Cognitive engineering principles in the design of human computer interfaces. In G. Salvendy (ed.), *Human-computer interaction* (pp. 11–16). Amsterdam: North-Holland.

O'Keefe, R. M. (1989). The evaluation of decision aiding systems: Guidelines and methods. *Information and Management, 17,* 217–226.

Patton, M. Q. (1986). *Utilization-focused evaluation.* London: Sage.

Pauker, S. G., and J. P. Kassirer. (1981). Clinical decision analysis by personal computer. *Archive of Internal Medicine, 141,* 1831–1837.

Phillips, L. D. (1990). Decision analysis for group decision support. In C. Eden and J. Radford (eds.), *Tackling strategic problems.* London: Sage.

Pitz, G. F. (1983). The human engineering of decision aids. In P. Humphreys, O. Svenson, and A. Vari (eds.), *Analyzing and aiding decision processes* (pp. 205–221). Amsterdam: North-Holland.

———. (1987). Evaluating decision aiding technologies for genetic counseling. In G. Evers-Kiebooms, J. J. Cassiman, H. v. d. Berghe and G. d'Ydewalle (eds.), *Genetic risk, risk perception, and decision making* (pp. 251–278). New York: LISS Inc.

Pitz, G. F., and J. McKillip. (1984). *Decision analysis for program evaluators.* Beverly Hills: Sage.

Potocnic, R. (1990). *Entscheidungstraining zu Berufs- und Studienwahl.* Bern: Huber.

Pots, P.W.G., F.D.J. van Schaik, and H. G. Sol. (1989). A gaming environment for testing decison support systems. In D. Murray-Smith, J. Stephenson and R. N. Zobel (eds.), *Proceedings of the 3rd European Simulation Congress* (pp. 673–678). Ghent, Belgium: SCS Eur.

Radcliff, B. (1986). Multi-criteria decision making—a survey of software. *Social Science Microcomputer Review, 4,* 43–60.

Riedel, S. (1986). Model-based evaluation of decision aids. Ph.D. dissertation, Carbondale: Southern Illinois University.

Riedel, S. L., and G. F. Pitz. (1986). Utilization-oriented evaluations of decision support systems. *IEEE Transactions on Systems, Man, and Cybernetics, 16,* 980–996.

Rohrmann, B. (1986). Evaluating the usefulness of decision aids: A methodological perspective. In B. Brehmer, H. Jungermann, P. Lourens and G. Sevon (eds.), *New directions in research on decision making* (pp. 363–381). Amsterdam: North-Holland.

Rosenthal, R., and R. L. Rosnow. (eds.) (1969). *Artifact and behavioral research.* New York: Academic Press.

Rossi, P. H., and H. E. Freeman. (1985). *Evaluation: A systematic approach* (3d ed.). Beverly Hills: Sage.

Rouse, W. B. (1984). Design and evaluation of computer-based decision support systems. In G. Salvendy (ed.), *Human-computer interaction* (pp. 229–246). Amsterdam: Elsevier.

Russo, E., and P.J.H. Shoemaker. (1989). *Decision traps.* Garden City, NY: Doubleday.

Sage, A. P. (1981). A methodological framework for systemic design and evaluation of computer aids for planning and decision support. *Computers and Electrical Engineering, 8,* 87–101.

Sainfort, F. C., D. H. Gustafson, K. Bosworth, and R. P. Hawkins. (1990). Decision support systems effectiveness: Conceptual framework and empirical evaluation. *Organizational Behaviour and Human Decision Processes, 45,* 232–252.

Schütz, H., and H. Jungermann. (1988). *Ansätze und Verfahren zur Hilfe bei persönlichen Entscheidungen.* Berlin: Bericht aus dem Institut für Psychologie der TU.

Seilheimer, S. D. (1988). Current state of decision support systems and expert systems technology. *Journal of Systems Management, 39,* 14–20.

Shadish, W. R., T. D. Cook, and L. C. Leviton. (1991). *Foundations of program evaluation.* London: Sage.

Sharda, R., S. H. Barr, and J. C. Mcdonnell. (1988). Decision support system effectiveness. A review and an empirical test. *Management Science, 34,* 139–159.

Shneiderman, B. (1987). *Designing the user interface. Strategies for effective human-computer interaction.* Reading, MA: Addison-Wesley.

Smith, M. L., G. U. Glass, and T. I. Miller. (1986). *The benefits of psychotherapy.* Baltimore: Johns Hopkins University Press.

Spezzano, C. (1985). Decision support software. *Popular Computing, 10/85,* 56–61, 122–124.

Sprague, R. H., and H. J. Watson. (1989). *Decision support systems—putting theory into practice.* Englewood Cliffs, NJ: Prentice-Hall.

Streitz, N. A. (1986). Cognitive ergonomics: An approach for the design of user oriented interactive systems. In F. Klix and H. Wandke (eds.), *Man-computer interaction research* (pp. 21–33). Amsterdam: North-Holland.

Stufflebeam, D. L., and A. J. Shinkfield. (1985). *Systematic evaluation.* Boston: Kluwer-Nijoff.

Sutherland, J. W. (1986). Assessing the artificial intelligence contribution to decision technology. *IEEE Transaction on Systems, Man, and Cybernetics, SMC-16,* 3–20.

Svenson, O. (1990). Some propositions for the classification of decision situations. In K. Borcherding, O. I. Larichev and D. M. Messik (eds.), *Contemporary issues in decision making* (pp. 17–33). Amsterdam: North-Holland.

Taylor, J., and W. Taylor. (1987). Searching for solutions. *PC Magazine* (September), 311–352.

Timmermans, D. (1991). *The effectiveness of MAU decision aids as a function of problem complexity.* Fribourg: Contribution to SPUDM-13.

Timmermans, D., C. Vlek, and L. Hendrickx. (1989). An experimental study of the effectiveness of computer-programmed decision support. In A. G. Lockett and G. Islei (eds.), *Improving decision making in organizations.* Heidelberg: Springer.

Vlek, C., and G. Cvetkovich (eds.). (1989). *Social decision methodology for technological projects.* Dordrecht: Kluwer.

Vlek, C., D. Timmermans, and W. Otten. The idea of decision support. This book.

van Schaik, F.D.J., and H. G. Sol (1990). Effectiveness of decision support systems. *Proceedings of the 23d Annual Hawaii International Conference on System Science* (3:50–58). Los Anamitos, CA: IEEE Computer Society Press.

von Winterfeldt, D. (1980). Structuring decision problems for decision analysis. *Acta Psychologica, 45,* 71–94.

von Winterfeldt, D., and W. Edwards. (1986). *Decision analysis and behavioral research.* Cambridge: University Press.

Wheeler, D. D., and I. L. Janis. (1980). *A practical guide for making decisions.* New York: Free Press.

Wisudha, A. (1985). Design of decision aiding systems. In G. Wright (ed.), *Behavioral decision making* (pp. 235–253). New York: Plenum Press.

Wittmann, W., and G. E. Matt. (1986). Meta-Analyse als Integration von Forschungsergebnissen am Beispiel deutschsprachiger Arbeiten zur effektivität von Psychotherapie. *Psychologische Rundschau, 37,* 20–40.

Wooler, S. (1982). Decision aid for structuring and evaluating career choice options. *Journal of Operational Research Society, 33,* 343–353.

Wooler, S., and B. Lewis. (1982). Computer-assisted careers counselling: A new approach. *British Journal of Guidance and Counselling, 10,* 124–136.

Wooler, S., and A. Wisudha. (1985). An educational approach to designing computer based career guidance systems. *British Journal of Educational Technology, 16,* 135–144.

Wortman, P. M. (1983). Evaluation research: A methodological perspective. *Annual Review of Psychology, 34,* 223–260.

Wottawa, H., and H. Thurau. (1990). *Evaluation.* Bern: Huber.

Zachary, W. (1986). A cognitively based functional taxonomy of decision support techniques. *Human-Computer Interaction, 2,* 25–63.

Zimolong, B., and B. Rohrmann. (1988). Entscheidungshilfetechnologien. In D. Frey, C. G. Hoyos, and D. Stahlberg (eds.), *Angewandte Psychologie—ein Lehrbuch* (pp. 624–646). Munich: Psychologie-Verlags-Union.

2

# The Idea of Decision Support

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Can we help people make better decisions? An unsuspecting Socrates attempting to understand this question might soon run into some troubling issues. First, what is a decision? Can one actually make decisions, or do they happen to you (and when, how)? Does decision making occur only in given choice situations, or may it also involve developing and structuring a problem? Wouldn't future good decision making require careful monitoring of the actual consequences of past and current decisions? Could the (im)possibility of identifying current events as consequences of earlier decisions be a basis for measuring problem difficulty?

Second, what are "better" decisions? Better than what should they be? Is the comparative baseline to be found in people's (whose?) unaided intuition or in some other customary way of making decisions? Under which conditions can unaided decision making fairly be considered to yield baseline decision quality? And should the help be substantive (advising others what they should decide) or procedural (telling others how they should make up their mind)?

Third, how could we establish that one decision is better than another? Should we look at the relative characteristics of the selected alternative? Are we to wait for the decision's consequences and judge its quality from them? Or should the process of making the decision guide our quality appraisal? There seems to be some value in all three types of quality criteria. So when and for which type of problem is one or the other type of criterion appropriate?

Fourth, who is "people"? The individual employee contemplating changing jobs, the patient facing a medical treatment, the company manager considering a new investment, or the policymaker selecting a site for a tech-

nological project? Whom are we designing decision support methods (DSMs) for? Or are the latter supposed to be generally applicable?

Fifth, what involves "help" in making decisions? Self-help or others' help? Personalized help or instrumented (computerized) help? Formalized help or heuristic help? Informational help, problem-structuring help, or option evaluation help? Wouldn't the specification of appropriate decision support require that one know where the difficulties, the pains, and the needs lie?

Sixth, do decision makers want to be helped? It depends, undoubtedly. What are people's perceptions of the quality of their own decisions? When do they need decision support? What triggers a call for help in decision making? Is it problem complexity, uncertainty about outcomes, importance of consequences, or some other set of problem characteristics? And don't we tend to link decision quality to personal conscientiousness and autonomy? If so, wouldn't this require that any DSM leave sufficient room for the user's own view and intuitions about the decision problem, or—as Toda (1980) has called it—someone's compositional rationality?

Seventh, who is "we"? The computer specialist who develops a program based on a well-known decision method? The counselor who designs a general problem-solving approach based on clinical experience? The substantive expert who lets the data drive a decision via straightforward if-then rules? Or the decision scientist who is offering theoretical models for making good decisions?

The design and evaluation of DSMs turns out to be the litmus test of human decision theory. From a marketing perspective, one would say that DSMs simply have to work and, thus, to be accepted by the user. The ultimate user criterion, therefore, would be the belief or feeling that a DSM helps make adequate, or better, decisions. From a scientific perspective, however, one would need to specify which DSM is appropriate where, when, and for whom, and why and to what extent it will support the making of good decisions. Above all, the decision theorist wants to present DSMs that are based on a defensible concept of a "good" decision. The quality warrant of any DSM should be implied by its underlying model or principles or by its empirical basis (e.g., "experience"). Only thus can supported decision makers be offered external quality standards, while the DSM designer is freed from the subjective whims of his or her clients.

## BASIC PROPOSITIONS CONCERNING DECISION SUPPORT

Let us delineate and model the concept of decision support (DS) itself while considering some of the questions posed above.

First, we propose to consider decision making as encompassing three global stages or components: (1) acquiring, retrieving, and/or selecting

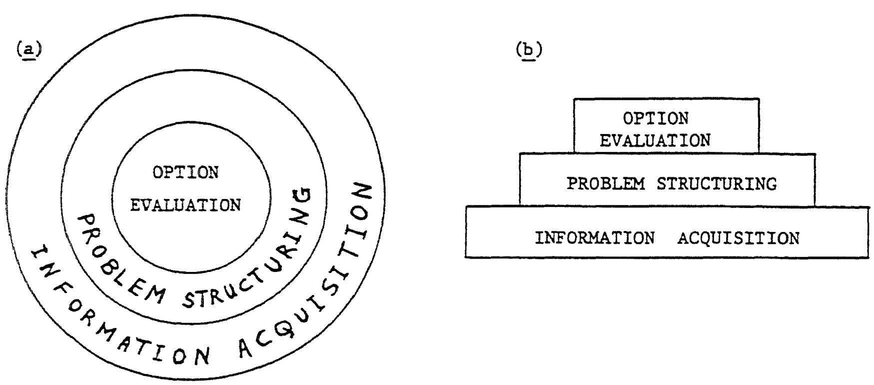
relevant information; (2) structuring the decision problem such that choice alternatives and their distinguishing features become visible; and (3) evaluating alternatives for their relative (expected) attractiveness. These are very much in line with Simon's (1960) intelligence, design, and choice phases. We should realize, however, that the three components are embedded (Figure 2.1a). Available information forms the outer context or base of decision making. This conditions but does not fully determine the way the problem is structured. The third component, option evaluation, in turn depends upon the other two. Figure 2.1b suggests that the three components may also be envisaged as forming a pyramid with three terraces decreasing in size while increasing in specificity. The highest and smallest terrace, involving coherent evaluation of given choice alternatives, is familiar ground for classical decision theorists.

Explicit DS may be addressed at all three components of Figure 2.1. Aimed at information acquisition, DS would imply that expert knowledge, from persons or documents, is provided such that the decision maker (DM) optimally knows the task environment in which a decision is to be made. When sufficient information is available, DS would involve a selection and ordering of decision-relevant elements such that a transparent, logical structure of the problem emerges. Finally, when a well-structured problem is given, DS would imply a coherent evaluation of choice alternatives in the terms suggested by the adopted decision model.

The general goal of DS is to canalize and direct the DM's cognitive process, so as to overcome the uncertainty about what would be an acceptable or the best course of action. In principle this may involve all three components represented in Figure 2.1.

The scheme of Figure 2.1 suggests the question of which type of DS

**Figure 2.1**
**General Components of Decision Making**




*Note:* Envisioned as embedded (*a*) and as forming a pyramid of supporting terraces (*b*).

would generally be most effective: providing relevant information, helping to structure the problem, or aiding the coherent evaluation of alternatives. The answer may be important for understanding why clients do or do not accept certain forms of readily available DS. For example, a multiattribute utility rating technique might be unsupportive of DMs who lack basic information. More important, the issue suggests that the decision-making state or status of any client be carefully (self-) diagnosed before embarking on any kind of DS.

Second, if DSMs are to have any practical significance, methodically supported decisions should be "better" than unsupported decisions. But to be sensible, this simple statement must imply a ceteris paribus proviso. For example, it would be unfair to evaluate any time-consuming DSM by comparing it with a quick-and-dirty intuitive choice process. Hence, also, an evaluation criterion like the convergence of intuitive (prior) and calculated (final) preferences concerning a set of decision alternatives seems a tricky one if one is unable to specify the way in which the intuitive preferences came about. In fact, the quality of supported decisions cannot be properly established if we cannot at the same time describe the quality of comparable unsupported decisions, in terms of criteria like quality of basic information, validity of problem structure, and coherence of option evaluation.

Third, effective DS should be directed at real clients who both need the help and are willing to accept it. The need for decision support may be indicated directly by potential clients themselves, who "can't solve their problem." It may be more generally, and more precisely, established by studying the quality of unaided decisions and decision processes. Thus, the descriptive modeling of human decision making is essential for the design and evaluation of prescriptive DSMs.

Clients' willingness to accept DS may depend on the nature of the problem. As a rule of thumb one may expect that simple decisions do not need to be supported, while overwhelmingly important problems cannot be fully supported. The expected success of DSMs, therefore, would seem to lie within the class of intermediately complex problems whose potential consequences do not involve strong emotional responses on the part of the DM.

The importance of real clients implies that it is somewhat problematic to make use of volunteer laboratory subjects for evaluating DSMs, since these generally cannot be considered really to "own" the decision problems presented to them. From a scientific point of view, controlled studies of DSM effectiveness are indispensable. The imaginary decision problems used should, however, be vividly representative of (the subject's) real life. And in the area of DS, experimental research should always be supplemented with observational field studies (see Rohrmann & Schutz, this book).

Another basic truth of successful DS is that the autonomy and the ultimate responsibility of the DM are always acknowledged. This again touches on the question of what would constitute a good decision. It seems safe to

assume that it is the DM who would be the ultimate judge of this. Wouldn't we therefore have to accept that a good decision may depend upon several things simultaneously? The most obvious of these are the perceived quality of the selected course of action, by itself or in comparison to competing options, and the (perceived) quality of the way in which the decision was reached. Note that both criteria may comprise elements from all three global components of DS (Figure 2.1): information acquisition, problem structuring, and option evaluation. We will return to the problem of evaluating decision quality.

Fourth, it would seem that the mode of DS and the mediating agent should be fine-tuned toward the nature of the problem and the characteristics of the DM. Highly personal decisions are perhaps better supported by a trusted adviser or via a self-help workbook, implying only a modest use of formalized methods. Business investments, on the other hand, may well require the use of computerized formal techniques applied to authorized input data. Ethical dilemmas such as often arise in health care settings may best be solved in a balanced expert-client interaction following an adopted decision procedure and subtask division. Whatever support is provided, it would seem that the modeling of the subject's decision problem, based on available information and preceding option evaluation, is the central element in the process of reaching a good decision.

The general idea of decision support unfolded thus far explicitly goes beyond Bayesian decision theory and the methodology of decision analysis. Most real-life problems are sufficiently ill defined to frustrate the rational intentions of any DM. The principal difficulty is that Bayesian decision theory does not provide a stopping rule for its analysis. Hence, it seems to imply that the decision maker must perform an endless explication of any problem before he or she can justifiably cut the knot and act toward achieving his or her substantive goal (Collingridge 1982). Compositional or synthetic, instead of analytic, rationality (Toda 1980) would often involve simpler or automated decision rules whose effectiveness is undisputable.

## TYPICALITIES OF UNAIDED DECISION MAKING

Is decision support needed, and would it be accepted by real decision makers? This may become clear when it is known how good or bad real decisions are in particular situations when the DM is not explicitly supported.

Descriptive research on decision making has yielded a general picture of people as limited, selective, and sequential information processors. Thus, they are reasonably capable of making relatively simple, adaptive decisions (how else would they survive?). But they are poor at making complex, strategic decisions causing significant changes in living conditions. Let us look at some evidence, with a view to specifying the conditions for DS.

Unaided-decision quality is strongly dependent on task complexity. The latter mainly depends on the number of choice alternatives, of critical uncertain events, and of relevant evaluative dimensions or attributes. Complexity also depends on the ambiguity surrounding any decision component, which may especially occur when a choice alternative has long-term and/or widespread consequences. Novelty and perceived complexity of a decision problem tend to go hand in hand; growing experience works to make an originally complex problem look simpler.

Limited information-processing capacity leads people to apply simplifying cognitive strategies to manage complex judgment and decision tasks (Tversky and Kahneman 1974; Einhorn & Hogarth 1981; Hogarth 1987). The more difficult the decision task is, the stronger is one's tendency toward simplification (Payne 1976, 1982; Payne, Braunstein & Carroll, 1978; Olshavsky 1979). Simplifying decision strategies are often effective, but they may also lead to systematic errors and defective choices.

The simplification of a decision process may be achieved in a number of ways (Park 1978): (1) by limiting the information to be evaluated, (2) by screening out a number of "unacceptable" or "infeasible" alternatives, (3) by using noncompensatory decision rules that do not require trade-offs, and (4) by reducing the number of categories on the attribute scales by which options are to be evaluated. For example, a ten-category attractiveness scale may be transformed into a three-point scale yielding "positive," "negative," and "doesn't contribute" judgments.

Human limited information-processing capacity inevitably leads to selective perception of problem elements. Salient and frequently occurring data are quickly noticed, recognized, and recalled. Selective perception may result in an incomplete representation of a decision problem, when not all feasible alternatives are identified and/or not all relevant uncertainties and evaluative dimensions are explicated. Selective information processing may also yield biased probability judgments based on distorted data sets. And it may underlie unreliable and inconsistent value judgments due to an unstable structure of goals, objectives and attributes.

Many people appear to adapt their cognitive strategies to the nature of the task (Brehmer 1976). Which decision strategy one employs depends on several factors, such as: personal experience, knowledge, and motivation; the importance of possible consequences, time pressure, and personal responsibility for the decision; and decision task complexity (Beach & Mitchell 1978; Christensen-Szalanski 1978). In agreement with these authors, Shugan (1980) contends that decision makers apply some kind of cost-benefit analysis whereby the time and effort required by a particular cognitive strategy are weighted against the importance of making an optimal decision. Under time pressure, people tend to use simpler and faster decision strategies; important decisions elicit a more elaborate approach (Malhotra 1982).

Rational decision models seem to provide good descriptions of decision

behavior in simple situations. With growing task complexity, however, unaided decision making begins to deviate systematically from the behavior prescribed by normative models (Payne 1976, 1982; Olshavsky 1979; Park 1978, Malhotra 1982). Johnson (1979) compared the cognitive effort demanded by different decision strategies applied to problems of varying complexity. It appeared that an increase in the number of choice alternatives did not enhance the cognitive demands of an elimination-by-aspects strategy (Tversky 1972) as much as it enhanced the effort required by an additive-differences strategy.

The efficiency of various decision rules has also been investigated by Thorngate (1980). In a computer simulation study, Thorngate determined how often a particular suboptimal rule yielded the option having the highest expected utility (assumed linear in money) for a series of choices among two-outcome gambles. It appeared that cognitively simpler decision rules sometimes yielded suboptimal choices but often indicated the optimal or a close-to-optimal alternative.

The use of simplifying strategies may lead to suboptimal decisions. Malhotra (1982) found that accuracy of subjects' choices decreased with increasing number of alternatives and evaluative dimensions. Paquette and Kida (1988) also considered how subjects deal with different decision strategies in problems of varying complexity. For each of a number of strategies, they determined efficiency as a function of time required and accuracy. A differential decrease in accuracy with increasing task complexity was found for the different strategies. The most efficient DMs turned out to be those who applied relatively simple strategies to relatively complex problems; they saved time, and their accuracy hardly suffered (cf. Thorngate's 1980 study discussed above). With increasing task complexity, the accuracy of choices under an additive compensatory decision rule decreased more strongly than under the less demanding elimination-by-aspects rule.

A significant cause of deficient decisions is stress due to sheer problem complexity, information overload, importance of consequences (risk), lack of hope for an acceptable course of action, shortage of time, and social pressure. The associated deficiencies are, respectively: simplifying decision strategies, selective use and neglect of information, undue weighting of negative aspects of consequences (risk avoidance), a defensive instead of functional attitude toward the problem, hypervigilant or panicky information acquisition, and unjustified conformity to others' opinions or enclosure in groupthink (Janis 1972). Janis and Mann (1977) have noted that stress—from whatever source—generally precludes what they call "vigilant information processing," which they equate to efficient decision making.

There are some other phenomena that restrict the quality of human decisions. Premature and rigid commitment to a chosen course of action would go against the mental openness that may be required for a needed course correction on the way (Staw 1981). Related to this, but more serious in de-

gree, is the power of addiction, which at an emotional-physiological level may pull a DM back into doing something that he or she does not want to do (any longer) at a conscious level (Sjöberg 1980). Finally, a natural peculiarity of human decision making is the discounting of future events, positive or negative. This explains, for example, why we do not easily pay immediate costs to secure future benefits and why we tend to be quick in reaping the fruits of today despite the associated long-term costs and risks (Björkman 1984).

In view of the nature of unaided decision making, one would say that explicit DS is to serve various functions. Especially for novel and complex decision problems, DSMs should help overcome the implications of cognitive limitations such as selective perception and retrieval of information, incomplete or biased definition of the problem, and unreliable or inconsistent evaluation of choice alternatives. The power of DS is that it extends the DM's informational, reasoning, and evaluative capabilities so as almost to make him or her operate as a simultaneous instead of a sequential information processor. Conversely, however, the power of experienced unaided DMs lies in the relative efficiency of simplifying strategies. Thus, it would seem that any recommendable DSM should not only result in optimal, or acceptable, decisions. It should also be efficient in the context in which the decision problem occurs.

## PROCESS COMPONENTS AND A PROBLEM TAXONOMY

The easiest distinction is between simple and complex decision problems or between well-defined and ill-defined problems. The suggestion was made that novelty of a problem correlates with its perceived complexity and lack of definition. For DS to be effective, it would be crucial to know why and in what respects a decision problem may be complex or ill defined. This knowledge would enable us to seek an adequate decision method and rule, the proper criteria, and the necessary information, and it might alert us to certain errors of judgment that would be likely to occur.

A general definition of a decision problem is as follows:

> A decision problem occurs when a decision maker: (a) notices a discrepancy between an existing state and a desired state, (b) has the motivation as well as (c) the potential to reduce this discrepancy, whereby (d) there is more than one possible course of action which may not be immediately available, (e) the implementation of a course of action demands an irreversible allocation of his resources, and (f) the utilities (of the consequences) associated with each choice alternative are partly or entirely uncertain. (Vlek & Wagenaar 1979, p. 257; adapted from MacCrimmon 1972).

This definition in principle applies to the worst-defined decision problem anyone might encounter. It would therefore be useful to sketch a functional decision process aimed at attacking (very) ill-defined problems. This is done

in Table 2.1, which reflects the problem-structuring and option-evaluation components of the general delineation of decision support given in Figure 2.1. Note that the option-evaluation part of the process is formulated in terms of Bayesian decision theory; it might well be filled in otherwise.

In terms of the (prescriptive) process model of Table 2.1, decision problems may be more or less complex or difficult to handle. This partly depends on task and situational characteristics and partly on personal resources and peculiarities; no problem can be defined independently from its owner. Let us consider ten problem variables—not all mutually independent—that may serve to categorize decision problems. These variables can be grouped according to whether they concern problem structuring, option evaluation, and the (social) context of the decision problem proper.

### Variations in Problem Structuring

1. *Availability of choice alternatives.* A possible course of action may be imaginable, but it may not (yet) be feasible. Alternatives may also become only sequentially instead of simultaneously available.
2. *Ease of consequence description.* Easy consequences may not be a problem; difficult consequences may call for special studies.
3. *Short versus long time horizon.* Relevant consequences may be fairly immediate or remote in time. The latter are often highly uncertain, and they pose special problems for their evaluation.

### Variations in Option Evaluation

4. *Single-attributive versus multiattributive consequences.* Utility assessment for these different types of consequences is quite different, and different techniques are available.

**Table 2.1**
**Successive Components of a "Conscientious" Decision Process**

| | |
|---|---|
| I. PROBLEM STRUCTURING | a. problem identification: establishing discrepancy between existing and desired states; goal analysis |
| | b. generation/search/design of feasible choice alternatives |
| | c. description of alternatives in terms of uncertain events, contingent choices and eventual consequences |
| II. OPTION EVALUATION | d. assessment of probabilities of uncertain outcomes and (optional) acquisition and processing of new information |
| | e. utility assessment in view of adopted goals/objectives; trade-offs among cost, risk and benefit dimensions |
| | f. overall evaluation and rank ordering of alternatives; (optional) revision and re-ordering after sensitivity analyses |

5. *Riskless versus uncertain or risky choice alternatives.* This is a classic taxonomic variable associated with fundamentally different decision models and with the specific subtask of probability and risk assessment.
6. *Internal versus external uncertainties.* This variable is nested under the category of risky decision problems. Internal (controllable) uncertainties depend upon the DM's skills and knowledge concerning a course of action. External (uncontrollable) uncertainties depend upon factors outside the DM's control, sometimes referred to as acts of God.
7. *Frequentistic versus nonfrequentistic event information.* This equally nested variable pertains to the availability of frequentistic experience (or statistics) about the outcomes of an uncertain event. In novel decision situations, experience is lacking and one has to assess probabilities by modeling a stochastic process or by constructing ad hoc scenarios.

In combination, varieties 6 and 7 define at least four rather different kinds of uncertainty (Kahneman & Tversky 1982; Hendrickx, Vlek & Oppewal 1989), which may underlie probability estimates (Figure 2.2b).

**Variations in (Social) Context**

8. *Degree of personal freedom of choice.* The DM may be more or less forced to select a particular course of action. This may be due to social pressure, to the sheer necessity of fulfilling basic needs, or to his or her being tied to an undesired habit or addiction. Freedom of choice brings with it personal responsibilities, and "responsible" DMs may need specific support.
9. *Number of involved persons.* This variable may overlap with variable 8: many others involved may mean little personal freedom. Variable 9, however, is primarily meant to indicate the number of persons involved in the possible consequences of a decision: will the costs, risks, and benefits be borne by the DM alone or by many others as well? In the latter case, the evaluation of consequences invites special considerations and techniques.
10. *Reversibility of decision or restorability of consequences.* Although the general definition says that a decision involves an irreversible allocation of resources, the possibility of reversing a decision and/or restoring its consequences when they occur significantly influences the importance of generating feasible courses of action and making a good decision. Irreversible decisions having unrestorable consequences amount to the purest of gambling situations. No DM likes this very much; most people cherish control and flexibility, before and after the die is cast.

The ten taxonomic variables and their division in three groups are summarized in the triptych of Figure 2.2. Here, all $2^{10} = 1{,}024$ theoretically possible types of decision problem have been conveniently reduced to just 26, labeled with the letters of the alphabet. Obviously, variations within the other two panels of Figure 2.2 should be considered once a decision problem has been characterized within a given panel.

The taxonomy suggested in Figure 2.2 does not explicitly address the in-

**Figure 2.2**
**Taxonomy of Decision Problems**

(A) STRUCTURING: variables 1-3

| description of consequences: | alternatives: directly available | | alternatives: not directly available | |
|---|---|---|---|---|
| | long t.h. | short t.h. | long t.h. | short t.h. |
| easy | a | b | c | d |
| difficult | e | f | g | h |

note: t.h. = time horizon

(B) OPTION EVALUATION: variables 4-7

| consequences: | | outcomes: riskless | outcomes: risky: external | outcomes: risky: internal |
|---|---|---|---|---|
| single-attributive | freq. | i | k | l |
| | nonfreq. | | m | n |
| multi-attributive | freq. | j | o | p |
| | nonfreq. | | q | r |

note: (non)freq. = (non)frequentistic

(C) CONTEXT : variables 8-10

| freedom of choice: | others involved: few | | others involved: many | |
|---|---|---|---|---|
| | irrev. | rev. | irrev. | rev. |
| large | s | t | u | v |
| small | w | x | y | z |

note: (ir)rev. = (ir)reversible

*Note:* Organized by groups of three or four characteristic variables (see text). The lowercase letters *a–z* indicate the various problem types.

formation acquisition component of DS (cf. Figure 2.1). This is because information acquisition is more often triggered by the recognition of a decision problem than that it leads into the problem by itself. Thus, the search for relevant information may unfold and intensify as one goes along the process components of Table 2.1. The nature of the information required depends upon the type of decision problem, as suggested by Figure 2.2.

The proposed taxonomy also does not seem to incorporate the classical distinction between static and dynamic decision problems (Edwards 1961; Toda 1962; Rapoport 1975). On the one hand, however, dynamism is represented in Figure 2.2—for example, if one considers a decision problem with choice alternatives not (all) immediately available (variable 1), a long time horizon (variable 3), internal and nonfrequentistic uncertainties (variables 6 and 7), and a reversible choice or restorable consequences (variable 10). On the other hand, a dynamic decision task is very hard to model formally and to support methodically (cf. Klieter 1975). Perhaps classical decision theory is not suitable for such problems, and some other perspective (such as decisional control theory) is required.

Figure 2.2 shows some resemblance to a detailed taxonomy for characterizing risk-decision problems, mapped out by Merkhofer (1987, pp. 50–53) in forty-four dimensions grouped into ten considerations: complexity of alternatives, complexity of relationships, nature of relevant information, outcome valuation complexity, constraints, decision-maker characteristics, organizational characteristics, sensitivity of public perceptions, controversy, and expectations. Evidently, the technological risk management problems considered by Merkhofer occur in a multiple-actor context of different kinds of information, complex action-consequence relationships, and possible reactions of an affected public. Similarly as for Figure 2.2, the challenge for decision supporters would be to map Merkhofer's (1987) problem dimensions into distinct decision approaches and methods.

The methodological implications of Figure 2.2 are numerous and diverse. For example, not immediately available alternatives (variable 1) must be searched or designed, and this may require special methods or strategies. Sequentially presented alternatives necessitate the formation of an accept/reject criterion (possibly multiattributive) based on the evaluation of an initial sample (subsequence) of candidates. For the utility assessment of consequences expected in different time periods (variable 3), so-called time preferences may have to be modeled. Methods for the assessment of probabilities (variables 6 and 7) depend on the kind of information available. The possibility of irreparable negative consequences (variable 10) puts special demands on the assessment of (dis)utilities, and it may require a specific decision rule or principle. In general, a specific type of decision problem in the framework of Figure 2.2 invites the use of a specific set of concepts and methods, often with assumptions of their own. Similarly, different cognitive

shortcomings and peculiarities may variously manifest themselves in connection with the varying types of decision problem. Decision supporters may want to beware of them.

Figure 2.2 should be a useful taxonomy insofar as it allows for a mapping of different types of decision problem into different decision models and/or different composites of decision methods and techniques. This taxonomy somehow incorporates or further specifies classical as well as more recent distinctions made by, among others, Edwards (1961), von Winterfeldt and Fischer (1975), Keeney and Raiffa (1976), Vlek and Wagenaar (1979), Von Winterfeldt (1980), and Larichev (1984).

Decision theorists may realize that Figure 2.2 is just too much (for what methods we have to offer), that there are strong ecological correlations among the ten variables (so that addition of a few more would not really matter), and that a more global and much simpler categorization of decision problems, models, and methods would be sufficient. This may be accepted for the moment, and we will consider such a strongly reduced division in terms of different levels of cognitive processing—or modes of decision making, evoked by strategic, tactical, and operational decision problems, respectively.

## LEVELS AND MODES OF DECISION MAKING

Rational decision analysis, the methodology developed from Bayesian decision theory (Raiffa 1968; Schlaifer 1969), has been elaborated in detail; von Winterfeldt and Edwards (1986), for example, discuss the interplay between analytical tools and cognitive processes. But decision analysis has not caught on as much as its originators had expected because it is too analytical for an effective approach to most practical decision problems. It also implies too static a conception of what a decision problem actually is.

Based on the ecological correlations among the ten taxonomic variables (and with apologies to the empiricists), we may consider judgment and decision making as occurring at three different levels of cognitive processing: the strategic, the tactical, and the operational. This is a pragmatic division that enables us to link major types of decision problems to different models and criteria for decision making.

Roughly, an *operational* (or "easy") problem is characterized by directly available choice alternatives, easy-to-assess consequences, a short time horizon, single-attributive consequences, no or only few uncertain events, internal (controllable) and frequentistic uncertainties (if present), a large freedom of choice, few other people involved, and a reversible choice and/or restorable consequences. Operational choice problems occur frequently, and they tend to be repetitive, so that (statistical) experience may be accumulated. They also tend to form a dynamic chain of (control) actions, together aimed at some greater-than-local goal.

*Strategic* (or "difficult") decision problems, on the other hand, are qualified by the opposite poles of the ten taxonomic variables: alternatives are not immediately clear, nor are the consequences; the latter are long term and multiattributive in nature; there are various uncertain events due to (uncontrollable) external factors with which there is little experience; there is limited freedom of choice; many others are involved; and an eventual decision would be irreversible while consequences could not be restored. Strategic choice problems tend to be novel or unique; frequentistic experience about them is lacking. Because of the external uncertainties involved and the long time horizon of relevant consequences, strategic decisions often amount to mammoth gambles.

*Tactical* decision problems are intermediately characterized between operational and strategic ones. In fact, operational, tactical, and strategic decisions form an embedding structure. Strategic choices determine the conditions under which tactical choices must be made. The latter, in turn, set the scene for operational choices, which are mostly of an adaptive nature (which is why we are good at them). The paradox of Bayesian decision theory is that it cannot be validly applied to unique or "experience-free" problems, whereas it is not dynamic enough to apply to the many chained operational problems making up much of daily life.

Operational, tactical, and strategic decisions are made at different levels of cognitive processing; they follow different modes of decision making; and they require different kinds of decision support. Operational choices are often habitual or automatic, following fixed if-then rules ("production rules"; cf. Anderson 1983). The programming of such rules gradually takes place as experience accumulates. The action-oriented routines underlying operational choices are highly effective, and disturbing the routine may lead to ineffective behavior. For the behavioral routine to remain in operation, an operational choice should generally have rewarding consequences.

Tactical choices are halfway between routine and unique. It would be too risky to make them automatically, but they are not serious enough to warrant an in-depth analysis. The proper way to make tactical decisions is by (sequentially) testing available courses of action against a set of acceptability criteria. This is traditionally called "satisficing" (Simon 1957), which may be done under different formal models.

Strategic decisions are the most complex and crucial ones. They therefore invite the application of a full-fledged decision analysis; the decision rule is to seek the optimal course of action, which has the highest expected utility. This is customarily labeled maximizing.

Thus, we have identified three levels and modes of decision making, each of them associated to a particular overall decision criterion. This is summarized in Table 2.2. The inference Table 2.2 allows us to make is that choices and decisions (philosophers may discriminate among them) may be made sooner and more automatically or later and more analytically. Nonanalytic

**Table 2.2**
**Three General Types of Decision Problems**

| type of problem | generic approach | nature of choice |
|---|---|---|
| strategic | analyzing | 'optimal' |
| tactical | standardizing | 'acceptable' |
| operational | automatizing | 'rewarding' |

*Note:* Most of these empirical criteria can also be used to assess the quality and effectiveness of a subject's own (unaided) way of decision making, which we study as a control condition with the aid of think-aloud protocols.

choices may not be bad at all, nor are analytically taken decisions always good. Each of the three ways of decision making—by routine, through satisficing, or via maximizing—has its own quality warrant—the strength of expected reward, the satisfying of explicit acceptance criteria, and the maximum expected utility, respectively.

The pragmatic three-level distinction proposed here is compatible with systematic distinctions made by others. Simon (1960) distinguishes between programmed and "open" (ill-structured) decision problems. One can consider a continuum of judgment and decision-making tasks, ranging from "intuitive" to "analytical." Fischhoff and associates (1981) systematically compare three different approaches for evaluating the acceptability of risks: expert judgment, bootstrapping the decision maker, and formal analysis. These would seem to run reasonably parallel to the (expert) automatizing, (explicit) standardizing, and (comparative) analyzing modes proposed in Table 2.2.

Svenson (this book) usefully separates four levels where decisions are reached by: (1) matching alternatives against an ideal or reference option, (2) applying some noncompensatory rule, (3) using a compensatory rule requiring trade-offs, and (4) an elaborate problem structuring, alternative-generation and maximization process. Humphreys and Berkeley's (1984) five-level system for analyzing decision problems seems to imply a decision-analytic *Einstellung;* it may be especially useful within the class of strategic choice problems, where analysis may be deeper and broader or shallower and narrower, depending on the extent to which the problem is already defined. We would suggest that their taxonomy parallels the three-component scheme of decision support given in Figure 2.1: information acquisition (their level 5), problem structuring (their levels 3 and 4), and option evaluation (their levels 1 and 2), respectively.

Taxonomies of decision making may be designed in terms of problem characteristics (as in Figure 2.2), in terms of process components (as in Table

2.1 and, more globally, in Figure 2.1), in terms of decision rules or criteria (as proposed by Svenson, this book), in terms of levels of abstraction or generality (or width of scope; as done by Humphreys & Berkeley 1985), and in terms of mode or type of decision making (as in Table 2.2), and as suggested by Hammond et al. (1980). To the extent that the term *decision making* has a generally accepted meaning, taxonomies pertaining to decision making should be interrelated. Table 2.3 demonstrates this (suggestively) for the taxonomies discussed.

In general, the more strategic a decision problem is, the broader and deeper analysis it provokes, the more constructive the decision process is, and the more maximizing the decision maker's overall strategy tends to be. Since this would require intense cognitive efforts and other resources, it is fortunate (and no accident, from an evolutionary point of view) that strategic decision problems are greatly outnumbered by tactical and operational problems, where satisfactory and rewarding choices are made following standardized and automated rules. We will survey formal models for standardized and analytic decision making, respectively. Formal models for automatized decision making belong to the realm of psychological learning theory. Although learning-theoretic principles may usefully serve to design a decision-making expert system, their treatment falls outside the scope of this chapter.

## WHAT CONSTITUTES A "GOOD" DECISION?

Theoretically the quality of decisions may be evaluated in two different ways. The first is to consider the value of the average outcome of a series of comparable decisions (each separate decision's outcome may be codetermined by good or bad luck). Because of the requirement that decision outcomes be easily identifiable, this quality criterion is best applicable to frequently occurring, relatively simple decisions that may be standardized. Note that a direct-outcome criterion would naturally fit the simplest riskless choices, which may be automated: "a good choice should (simply) have a rewarding outcome." Outcome criteria relate to a DM's substantive rationality.

The second way is to evaluate a decision by its procedural rationality. This is especially important when it is difficult or impossible to trace a decision's actual consequences, either because they occur too far into the future or because they may also be attributed to other decisions. This is usually the case with relatively rare and complex decisions that elicit analysis.

Decision rationality is not easy to define. According to Toda (1980, p. 139): "In my opinion, 'rational' is an adjective meaningfully applicable only to the *principle or rules* under which a purposive system operates. A principle or rule is rational if and only if it makes the system function (almost) optimally for a given context and under given constraints." Four kinds of rationality may be usefully distinguished:

**Table 2.3**
**Suggested Parallelisms among Different Taxonomies of Decision Making**

| type of decision problem | analytic level of abstraction (H. & B. 1985) | mode of cognitive processing | formal decision strategy | focus of decision process (Svenson, this vol.) |
|---|---|---|---|---|
| strategic | 5. exploring 'small worlds' | analyzing ("criteria-experts choice") | maximizing | |
| | 4. varying problem structuring | | | 4. construction of new options scenarios, preferences |
| | 3. accommodating an adopted problem structure | | | 3. conscious evaluation, by compensatory rules, of given set of options |
| | 2. sensitivity analysis ("what if?") | | | |
| | | [above this line decision support should be problem-specific] | | |
| | | [below this line decision support may (begin to) be standardized] | | |
| tactical | 1. direct evaluation ("best assessments") ? ↓ ? | standardizing | satisficing | 2. evaluation by reference to 'easy' standards, noncompensatory rules, stereotyped trade-offs |
| | | [below this line no decision support is needed or useful] | | |
| operational | | automatizing ("holistic choice") | rewarding | 1. similarity matching to reference option ? ↓ ? |

*Note:* According to problem type, level of analysis, mode of cognitive processing, decision strategy, and focus of decision process, respectively. See text. H & B refers to Humphreys & Berkeley (1985).

1. *Representational rationality:* Knowing the decision task environment.
2. *Goal-value rationality:* Knowing one's goals, objectives, and values.
3. *Methodical rationality:* Coherent assessment of decision inputs and use of decision rule.
4. *(De)compositional rationality:* Striking an adequate balance between intuitive and analytical judgment.

The first three can be maximized; one may always try to improve one's knowledge of the relevant "small world" and the elaboration and consistency of one's value system, and to refine and strengthen the assessment of inputs for the decision process. The fourth kind of rationality, however, somehow spoils the game. Neither an overanalytic nor a too superficial consideration of one's problem yields the "best" decision. Under the principle of (de)compositional rationality, a balance is required between intuitive synthesis, which may cut (or keep) the process short, and prolonged analysis, by which it may be paralyzed.

Note that both representational and goal-value rationality reflect substantive rationality: one knows the (small) world and one's own values, and this is the best warrant for obtaining good decision outcomes. In contrast, methodical and (d)compositional rationality are reflections of procedural rationality. Given what one knows and does not know, the assessment methods, depth of analysis, and decision rule followed guarantee that an optimal decision is made.

Rationality works out differently for different types of problems. For relatively simple problems that may be standardized, representational and goal-value rationality have somehow been filled in already (in the past); the problem is well known, and one largely knows what one prefers. This is why methodical rationality may be laid down in fixed rules for judgment and decision making. Thus, the fourth kind of rationality is strongly compositional or synthetic.

For complex, strategic problems, however, methodical rationality should be dominant since it fulfills the crucial function of bringing representational and goal-value rationality up to the required level. In other words, one tries to structure and evaluate the decision problem as coherently as possible, and this demands considerable analytic or decompositional efforts (the fourth kind of rationality).

Within classical decision theory, the concept of rationality has been operationalized in terms of a handful of axioms applicable to well-defined decision problems (see Krantz et al. 1971; also listed in Vlek & Wagenaar 1979, p. 274). For example, *decidability* implies that a DM for any pair of choice alternatives, A and B, can indicate that he or she either prefers A or B or is indifferent between the two. *Transitivity* means that the preference pattern for any three or more options is not cyclic: when A is preferred to B and B to C, then A is also preferred to C (instead of C to A). *Dominance* in-

volves that a DM facing two options always prefers the option evaluated as at least as good as the other in all respects and as better than the other in at least one respect. The *sure-thing principle* states that the preference relation among two options having uncertain consequences is independent of the value of a fixed consequence ("sure thing"), which follows the occurrence of a particular outcome of an uncertain event, no matter what one chooses.

Formal decision models and methods differ in the degree to which they are tuned toward satisfactory or toward optimal choices. Satisficing as an overall decision strategy involves a choice in favor of an "acceptable" option that is considered "good enough" (for the moment): this notion reflects the importance of compositional, standardized rationality. An optimizing decision strategy is aimed at selecting the best possible course of action; it is an operationalization of decompositional, problem-specific rationality. Formal models of decision making for problems that have already been defined are surveyed in the next section.

So far it would appear that decisions are "good" to the extent that they are rational (which means something different for simple and for complex decisions). Thus, a particular DSM might be evaluated as good to the extent that it helps one make rational decisions. However, what would make you *believe* that a given DSM would lead you to a rational decision, and would the DSM's inherent rationality be compatible with the rationality you see fit for your decision? And do you think that your actual problem can be structured and evaluated rationally at all? In other words, shouldn't we also consider more pragmatic and specific criteria for evaluating the quality of decisions and of DSMs? Yes, we should, and Rohrmann and Schutz's contribution to this book (Chapter 1) testifies to this.

In our own empirical research (Timmermans, Vlek & Hendrickx 1989) we evaluated computer programs for decision support (De Hoog's 1983 MIDAS; Pitz's 1987 DECAID; and Sonnenberg & Pauker's 1987 DECISION MAKER; see also Lau, Kassirer & Pauker 1983) by relying on four main sets of variables: (1) process characteristics such as time needed (per component), number of attributes used, and number of changes after sensitivity analysis; (2) robustness of the final choice made, assessed in terms of the subject's trust and acceptance, possibly against post hoc criticisms by others; (3) changes in the subject's view of the decision problem, such as through deeper understanding; and (4) personal satisfaction with the decision method followed, with specific comments on separate components (e.g., "I find the assignment of weights the most burdening subtask"); here, the personal autonomy "respected" by the DSM may play an important role.

Naturally, these empirical assessments come on top of the DSM's inherent rationality characteristics that mainly depend on the underlying decision model. And thus the concept of decision quality or DSM effectiveness appears to be a multidimensional one, which suggests that one might well utilize multiattribute utility models to support one's comparative evaluation of decision aids (see also Reidel & Pitz 1986 and Pitz 1987, who extensively

discusses the evaluation of decision aids). Ozernoy (1988) considers the selection of an appropriate multiattribute decision method under a limited hierarchy of objectives: (1) mutual correspondence between the method and the decision problem, (2) validity of the method's assumptions regarding DM preferences and compatibility with preference information, and (3) resource demands (e.g., costs, time) of the method.

## FORMAL MODELS OF DECISION MAKING

In order to delineate and operationalize the concept of decision support, we have thus far taken a broad view resulting in various taxonomic considerations and a circumscription of what constitutes a "good" decision. In this section we narrow down to the formal models that provide practical tools for decision support: satisficing models for "standardized" decision making and Bayesian decision analysis for "maximizing" choices.

### Satisficing Models: Utilizing Acceptance Rules

This class of models provides operationalizations of more or less complicated if-then rules. An example is: *"If* the annual costs are low and the bike is a reliable mode of transport, if the distance isn't too large, the trip itself not too strenuous and the weather is fair often enough: *then* I judge regular bicycling to and from my office to be an acceptable course of action."

Such testing methods are applicable only when several conditions are fulfilled. First, obviously one or more choice alternatives should be available. Second, the DM should be able to evaluate these in terms of a set of measurable variables. Third, a value or utility function must be defined on each variable such that acceptability judgments or trade-offs against other variables can be made. Fourth, when there is more than one variable, a combination rule must be adopted that indicates how the judgments on the separate variables are combined into an overall statement: accept or reject this option. Fifth, when one or more options appear to be judged acceptable, a supplementary decision rule is needed in order to make a singular choice.

Methods for testing options against acceptance criteria are thus aimed at (only) satisfying the DM. In principle, the decision process ends as soon as an acceptable option has been identified. Only when alternatives are easily available (generated, presented, or designed) may one attempt to select the "best" option from the subset of acceptable ones. Therefore, a sequential presentation or confrontation of alternatives would be sufficient for a satisficing model to apply. At every instance one actually has three options: (1) accept this alternative, (2) reject it and continue searching for an acceptable one, and (3) reject it and adhere to the status quo (do nothing further).

Testing choice alternatives one by one against a set of acceptance criteria can be a very efficient and time-saving decision method. Crucial questions,

however, are: is the DM using clear and valid enough acceptance variables; does reliance on the adopted criteria indeed result in good decisions; and are the chosen criteria jointly sufficient for making singular choices?

Testing options against acceptance criteria amounts to following a standardized decision rule. The selection of relevant variables and the adoption of a combination rule, therefore, involve a set of prior (meta-) decisions by which the rule is, or ought to be, calibrated to the (statistical) database that lends it its validity. Revision of the standards-testing rule may be regularly needed as time goes by and experience with additional cases accumulates. Thus, the good decision maker here exploits his or her knowledge of the (small) world and of his or her own positive and negative experiences (i.e., his or her substantive rationality). This again demonstrates that standards-testing models of decision making are best suited for relatively simple, frequently occurring decisions that allow a DM to evaluate their quality by considering actual decision consequences—on the average, that is.

There are several different satisficing models and rules. Suppose that $x_1$, $x_2$, and $x_3$ are selected variables on which $x_{c1}$, $x_{c2}$, and $x_{c3}$ have been set as acceptance criteria. The score profiles of two options, $O_i$ and $O_j$, may then be given as $[x_{i1}, x_{i2}, x_{i3}]$ and $[x_{j1}, x_{j2}, x_{j3}]$, respectively. Following the conjunctive model:

$$O_i \rightarrow \text{Acc, if } x_{i1} \geq x_{c1} \textit{ and } x_{i2} \geq x_{c2} \text{ and } x_{i3} \geq x_{c3}, \tag{2.1}$$

where Acc stands for "is judged acceptable." When $O_i$ and $O_j$ both appear to be acceptable, a supplementary decision rule may be:

$$O_i \,.\!> O_j, \text{ if } f\,[x_{i1}, x_{i2}, x_{i3}] > f\,[x_{j1}, x_{j2}, x_{j3}], \tag{2.2}$$

where .> indicates "is preferred to." The simplest form of $f$ is,

$$O_i \,.\!> O_j, \text{ if } x_{i1} > x_{j1} \textit{ and } x_{i2} > x_{j2} \textit{ and } x_{i3} > x_{j3}, \tag{2.3}$$

but this (strong) dominance rule will not often be applicable in practice. More convenient supplemental ways to decide among conjunctively acceptable options are to sharpen the acceptance criteria used in formula 2.1 or to use any of the other satisficing models given below, notably the compensatory weighting model (a primitive version of the weighted-additive utility model; see Von Winterfeldt & Fischer 1975). According to the disjunctive model:

$$O_i \rightarrow \text{Acc, if } \textit{either } x_{i1} \geq x_{c1} \textit{ or } x_{i2} \geq x_{c2} \textit{ or } x_{i3} \geq x_{c3}. \tag{2.4}$$

That is, $O_i$ needs to be "(very) good enough" in only one of the relevant variables in order to be judged acceptable. When $O_i$ and $O_j$ would both be

acceptable following this model, again a supplementary decision rule would be required.

The conjunctive and disjunctive satisficing models may be combined in several ways, as, for example when $O_i$ is accepted only if it exceeds $x_{c1}$ *and either* $x_{c2}$ *or* $x_{c3}$, which may both be criteria of "excellence." Both models in fact are extreme forms of the compensatory weighting model, which prescribes the testing of a weighted combination of an option's scores against one overall acceptability criterion (possibly being a weighted combination itself):

$$O_i \rightarrow \text{Acc, if } b_1x_{i1} + b_2x_{i2} + b_3x_{i3} \geq C, \tag{2.5}$$

where $C$ may either equal $b_1x_{c1} + b_2x_{c2} + b_3x_{c3}$ or be an independent overall criterion value. Formula 2.5 implies a simple weighted addition of an option's scores on the relevant variables. Various more intricate combination rules are possible, but these may not be so easily interpretable from a decision-theoretic or a psychological point of view. In case $O_i$ and $O_j$ both appear to be acceptable, formula 2.5 can be transformed into a supplementary decision rule:

$$O_i \,.\!> O_j, \text{ if } b_1x_{i1} + b_2x_{i2} + b_3x_{i3} > b_1x_{j1} + b_2x_{j2} + b_3x_{j3}. \tag{2.6}$$

This is the general and currently most popular maximizing decision rule for multiattributive, riskless choices, by which all available alternatives may be ordered following their relative attractiveness. The assumption is that $x_1$, $x_2$, and $x_3$ are (commensurable) utility scales whose values do not interact.

The three models discussed so far may be used to evaluate single choice alternatives that must be accepted or rejected. The following decision rules can only be applied to a set of two or more options.

*Elimination-by-aspects* (EBA, originally a descriptive probabilistic choice model; Tversky 1972) implies that the relevant variables are first ordered by importance and an acceptance criterion is set on each variable. Then all options are considered with respect to the most important variable, say $x_1$, and an option $O_i$ is rejected when $x_{i1} < x_{c1}$. The remaining options are tested next against the second-most-important variable, say $x_2$, and an option $O_j$ is rejected when $x_{j2} < x_{c2}$. In this way all (remaining) options are tested against all successively less important aspects until only one option is left that has (thus far) survived all acceptability tests. Further tests of this option, down the remaining order of aspects, would not make sense.

The elimination-by-aspects model has a "maximizing" cousin in the form of the *lexicographic rule,* in which all variables are ordered by importance but no acceptance criteria are set. All options then are judged with respect to the most important variable, and the (clearly) most attractive one on that variable is selected, whereby the decision process ends. Only if two or more

options are (about) equally attractive on the first variable does one proceed to evaluate (only) those with respect to the second variable. This process goes on as long as two or more options are judged to be equally good on successively less important variables. The first option to win out (clearly) as one goes along the hierarchy of variables is selected. Thus, the lexicographic rule is not a fully maximizing decision rule; it ignores lower-ordered variables on which once-rejected options may score very attractively. Neither, however, is it a genuine satisficing model, as it implies comparative judgment of options on the relevant variables. Thus, it would not be suitable for determining whether a given option would be acceptable by itself. Both the elimination-by-aspects and the lexicographic decision rules are clearly non-compensatory.

### Maximizing Models for Riskless and Risky Choices

This book is about decision analysis and decision-aiding software. Thus, the multiattribute utility model and the expected utility principle are getting a lot of attention, since these standard models from classical decision theory have inspired many software designers. We will therefore keep this section short and refer, when necessary, to a few well-known and easily accessible textbooks or journal articles.

To decide among riskless multiattributive alternatives, a straightforward model is the compensatory weighting or weighted-additive utility model given in formula 2.6, where $x_{ik}$ represents the utility of $O_i$ relative to variable $k$. The variables $x_k$ ($k = 1 \ldots r$) are customarily taken to be option (or rather consequence) characteristics such as income, travel distance, freedom of initiative, and variability of tasks associated with a given job option. They may also be time periods, distributional targets (e.g., a group of customers), or goods obtainable contingent upon outcomes of an uncertain event (in which case the outcome probabilities would logically serve as importance weights). In reality, the utility of a decision consequence may easily depend on a combination of its inherent characteristics, the time period in which it obtains, the person(s) to whom it is allocated, and the contingency that produces it. It would not be an easy task to model this formally, let alone to assess the various utility components empirically.

A rather different model for riskless choices is the lexicographic decision rule. With this and the basic-weighted-additive utility model, one could come up with some interesting and perhaps useful variants. This seems a little tricky psychologically, since DMs might lose their understanding for what is to be done. The resulting variants may well turn out to be domain specific.

Maximizing expected (multiattribute) utility is *the* principle of rational individual choice. To do this, one needs to confront a well-defined decision problem having uncertain consequences: anything that may be formally rep-

resented as a choice among gambles. This implies that the utilities of consequences can in principle be assessed, as well as the outcome probabilities associated with the uncertain event(s).

Taking the expected utility,

$$EU(O_j) = \sum_{i=1}^{n} p_i{*}u_{ij} \tag{2.7}$$

(where $p_i$ is the outcome probability and $u_{ij}$ the utility of what would be obtained if $O_j$ is chosen and outcome $i$ would occur), would subsequently make it simple, through rank ordering, to identify the "best" course of action. The $u_{ij}$ may, of course, be assessed in a multiattributive way, using, for example, the model given in formula 2.6.

In combination with formula 2.6, formula 2.7 is the foundation of Bayesian decision analysis, a rational methodology, which also pertains to so-called predecisional stages (Table 2.1) but which revolves especially around option evaluation through utility and probability assessment and with application of sensitivity analyses. The methodical instruments of decision analysis are grafted upon several analytical steps (Matheson & Howard 1968; Keeney & Raiffa 1976), which may be ordered as follows.

1. Analysis of goals and objectives, possibly going along with a description of the status quo.
2. Structural modeling of the decision problem.
3. Probabilistic or uncertainty analysis.
4. Value or utility analysis.
5. Optimization, including sensitivity analysis.

Let us briefly consider each of these.

In a *hierarchical goal* (or objectives) *analysis,* the DM may gradually decompose and concretize one or a few general goals into a comprehensive and coherent set of specific value or utility attributes. These may later serve to evaluate the consequences of given alternatives. But in ill-defined situations, they may also suggest the concrete actions that might be undertaken to achieve adopted goals. To evaluate suggested options with respect to their feasibility, an analysis and description of the current situation may be required.

*Structural modeling* of the decision problem is aimed at clarifying the relationships among current options, uncertain events, possible contingent choices, and eventual consequences. Modeling may be done in terms of a decision matrix of options by attributes, a decision tree diagram formalizing the set of scenarios involved, or an influence diagram (see Schachter 1986; Merkhofer 1987, p. 105).

During *uncertainty analysis,* probabilities are estimated and assigned to possible outcomes of relevant uncertain events. Either in this stage or conditional on later sensitivity analysis, one may find that the assessed probability distributions are not informative enough. The acquisition of additional information may be considered, the expected value of that information (and the choice to collect it) may be determined, and posterior probabilities may be computed, with the help of Bayes's theorem (Edwards, Lindman & Savage 1961; Lindley 1984). During uncertainty analysis the informational basis for probability assessment has to be carefully identified, so that it becomes clear whether one may rely on the logical, the frequentistic, or the personalistic interpretation of the probability concept (cf. the variants of risky decisions distinguished in Figure 2.2).

*Value* or *utility analysis* serves to assign judgments of relative attractiveness to the possible consequences of a set of choice alternatives. This may be done in various ways, depending upon how easy (or few-dimensional) one considers the task to be and how conscientiously one wishes to evaluate (Keeney & Raiffa 1976; Vlek & Wagenaar 1979; Lindley 1984; and von Winterfeldt & Edwards 1986 provide systematic treatments of utility assessment). Multiattribute utility analysis may well start with a hierarchical goal analysis yielding the specific set of attributes to be used. Or it may be founded on a series of triadic comparisons of choice alternatives whereby their discriminative characteristics may come to the light (Humphreys & McFadden 1980). Thus, utility analysis may incorporate a specific kind of problem structuring. Once the relevant attributes have been identified, a simple weighted-additive aggregation rule such as formula 2.6 may yield the overall utility of a given decision consequence or (riskless) choice alternative.

*Optimization analysis* involves the computation of expected (multiattribute) utilities and a rank ordering of alternatives following their relative attractiveness. It also may imply sensitivity analyses during which judgmental inputs to the analysis are systematically varied to check the sensitivity of the computed preference order for variations in one or more "doubtful" assessments. The need for and the possibility to perform sensitivity analyses provide powerful reasons for the computerization of decision analysis. In fact, a single run through a decision problem is hardly interesting if one knows that one can (and should, often) iterate the expected utility calculations with repeated corrections and/or adaptations of probability and utility judgments. Sensitivity analysis may also pertain to structural problem elements, such as the specific subset of an original list of relevant attributes in a multiattribute utility analysis.

Expected (multiattribute) utility maximization thus functions as the revolving door of rational decision analysis. For decision problems involving uncertain outcomes, however, there also are some other decision rules. Despite their maximizing character, these are usually considered suboptimal, as the uncertainties involved are ignored.

The *maximax payoff* rule stipulates that one should first determine the maximum possible payoff under each choice alternative and then maximize across options while considering only the maximal payoffs. In contrast, the *maximin payoff* rule prescribes first looking at the minimum possible payoff per alternative and then maximizing across options with disregard of other possible payoffs. The *principle of insufficient reason* holds that one behaves as if all uncertain outcomes are equally likely, so that the "best" alternative can be identified by taking the average expected payoff per option. Finally, the *minimax regret* rule first involves a computation of regret values—the difference between the highest payoff across alternatives and every other payoff, under each uncertain outcome. Next, the maximum regret value per alternative is identified, and the "best" option is determined by minimizing across options while considering only the maximum regret values.

As Cooms, Dawes, and Tversky (1970, chap. 5) have shown, maximax and maximin payoff, minimax regret, and "insufficient reason" may lead to different "best" choices among a given set of alternatives with numerically evaluated consequences. For a truly equiprobable outcome set, the principle of insufficient reason would be equivalent to expected value (or utility) maximization under a uniform probability distribution. These rules for decision making under ignorance may well be used as a basis for decision support, provided that one is aware of the "evaluative mood" (or meta-strategy) that they imply.

### Multimodel Decision Approaches

As suggested in Table 2.2, "rewarding," "satisficing," and "maximizing" choice behavior is inherently embedded: most of us frequently face routine operational decision problems flowing from regularly occurring tactical decisions; only rarely do we have to take truly novel and complex decisions that set the stage for a whole new sequence of tactical and operational choices. Thus, a full-fledged decision analysis seems called for only infrequently; standardized and automatic decision making are the rule rather than the exception.

However, the shifting up and down mode of decision making (Table 2.2) occurs not only between different types of problem; it may also occur within a given class of decision problems, among different DMs, and even within a single decision process. For a given type of problem, such as the selection of a job applicant, the reliance on analytic versus synthetic judgment may well depend on the importance of potential consequences (a variable not incorporated in the taxonomy of Figure 2.2) or on the motivation and seriousness of the DM. Important problems invite analytical judgment; motivated and serious DMs tend toward the same. But a DM who relies on synthetic judgment may do so through experience, not because he or she is unmotivated or lazy. Experience with a particular class of problems drives you down the

different modes of decision making: from slow, conscientious analysis to fast, effective synthesis. These considerations need to be taken into account when selecting a DSM for solving a given decision problem.

More directly relevant for professional decision supporters is the possibility of combining a satisficing and a maximizing decision model within a single decision process. The satisficing rule would then be used for the relatively easy task of screening out acceptable options. This might greatly reduce the effort required to complete the process with a subsequent rule, by which the remaining alternatives would be evaluated in a comparative, compensatory manner.

One step beyond this satisficing-then-maximizing decision approach lies a modular decision support system that would allow the DM to apply a rational sequence of decision rules, such as elimination of dominated alternatives, testing options against (strict) acceptance standards, elimination by least attractive aspects (such as certain risk dimensions), and expected multiattribute utility maximization with respect to the remaining subset of alternatives.

A practical decision philosophy resembling this appears to be developed in radiation protection policy (ICRP 1977). Here, the acceptability of a certain radiological application is determined by applying three "principles": (1) justification: "Are the intended benefits really necessary?" (2) ALARA: "Is the radiation level as low as reasonably achievable?" and (3) tolerability: "Is the unavoidable radiation level below maximum tolerable limits?" The order in which these principles should be applied is still being debated: it also seems possible to apply them conjunctively. Radiation protectionists do not seem to consider applying them in a compensatory manner, as when a higher radiation risk is deemed acceptable so long as the benefits are badly needed (which, of course, regularly happens in medical settings).

The importance of taking a multimodel approach as the basis for designing explicit decision support should not be underestimated. The flexibility among different modes and rules of decision making would be appealing to many users, if only because it would make the DSM as a whole to reflect some basic characteristics of users' own unaided way of making decisions.

## SOME PROBLEMS AND METHODS OF SOCIAL DECISION MAKING

Rational decision theory, and thus Bayesian decision analysis, is inevitably individualistic. For a given set of alternatives, maximizing expected (multiattribute) utility may yield a certain "best choice" for person A, but B may come up with another "most preferred" option, and this again may be different for person C. Obviously, people have different preferences; this is only partially attributable to differences in beliefs and underlying information; it is often due to differences in taste; and *de gustibus non est disputan-*

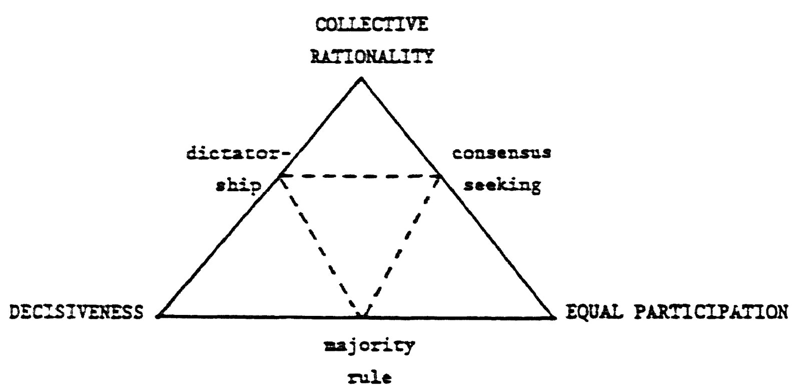
*dum* (a Latin way of respecting the interpersonal incomparability of utilities).

It is a decades-old finding of social choice theorists (Arrow 1951; Sen 1970; see also Blair & Pollak 1983; Bezembinder 1989) that there does not exist a nondictatorial method for the rational amalgamation of differing individual preference orders with respect to a given set of choice alternatives. This means that any practical social voting method applied to three or more options could not be adopted a priori by all parties involved (who would declare to "accept" the result whatever this would be), since the result may not be paradox free (e.g., it may contain social intransitivies) or it may demonstrably be method dependent.

Three principles of social choice and three practical solutions are schematically pictured in Figure 2.3 (from Vlek & Cvetkovich 1989, p. 308). Each solution (lowercase letters) meets only two principles (capital letters) while violating the third one (in the opposite corner). Since dictatorship is unpopular in democratic communities while consensus seeking is notoriously undecisive, majority rule is a widely accepted social decision method. This, however, yields a guaranteed social preference order only when two options are considered at a time. Thus, majority rule usually amounts to voting for or against a proposed course of action, and the order in which two or more alternatives-proper are put on the voting agenda may significantly affect the selection of the "socially most preferred" option.

Majority voting, then, usually yields one collectively preferred option, which has to be accepted by all those who did not personally rank it as "best." This suggests that prior application of an individual satisficing rule by each party may considerably reduce potential social conflict. Individual

**Figure 2.3**
**The Trilemma of Social Choice**




*Note:* Represented by three principles (solid triangle and capital letters) and three practical solutions (dashed triangle and lowercase letters), each meeting only a pair of them.

satisficing would reduce the set of alternatives to be subjected to majority voting, provided that all parties agree to exclude from voting any alternative that is (strictly) unacceptable to any party.

Given the individual decision support schemes of Figure 2.1 and Table 2.1, what could one undertake to support social decisions in groups and organizations? First, most social decision problems are sufficiently ill defined for social choice theory (which pertains to given choice sets) to be only partially relevant. Our multicomponent scheme of decision making would seem to apply a fortiori to group and organizational decision making, where processes of information acquisition and exchange and of problem structuring very much condition the set of choice alternatives to be socially evaluated. Thus, again the question arises, Which component of the total process would need to be supported most?

Second, since there is no collectively rational decision method, one would think that a pragmatic approach could be useful, in which the judgments of substantive experts and the preferences of those potentially affected by a decision's consequences are brought together under the coordination of some ultimately responsible decision maker (maybe a professional "knot cutter"). On a small scale this could, for example, yield concrete solutions to difficult doctor-patient (or doctors-patient-family) decision problems in medical settings. On a larger scale, as in connection with new technological systems or processes, one might have to go by a well-organized social decision procedure in which experts, special interest groups, and public representatives work together in a series of meetings aimed at exchanging information, structuring the decision problem, and (somehow) collectively evaluating the available choice alternatives. (Vlek & Cvetkovich 1989 also summarize and comment upon several recent approaches proposed by others. Friend & Hickling 1987 provide an artistic exposition of their strategic choice approach.)

Third, we should be aware of the fact that social decision makers must overcome two general problems: (1) each party has an individual judgment problem, and (2) all parties together face a social interaction and aggregation problem. Thus, effective social decision support may partly consist of methods and rules taken from individual decision theory; partly it should supplement these with (or incorporate them into) a set of procedures and techniques for information exchange and communication among parties, for aggregate problem structuring, and for joint evaluation of feasible courses of action.

Naturally, the individual decision quality criteria should be supplemented with – or partly replaced by – criteria for "good" social decisions. Here one would especially think of consensus measures regarding what would be relevant information, an adequate problem structure, and valuable consequences. Also important would seem the extent to which the supported decision procedure is capable of building trust in the course of action even-

tually selected. A trusted social decision procedure may strongly encourage individual parties to swallow their initial objections to a chosen alternative they do not or did not like.

We cannot ignore the voluminous literature on organizational decision processes (see, e.g., Bass 1983; Wright 1985, pt. 3). What lessons for decision supporters can be learned here? Descriptive research has yielded the recurrent conclusion that complex decisions in organizations tend to be taken along several recognizable stages. For example, Mintzberg, Raisinghani, and Theorêt (1976) described twenty-six important decision processes as following problem identification, development of alternatives, and evaluation and selection. In a more elaborate descriptive study, Nutt (1984) analyzed seventy-three organizational decision processes following a five-stage model: (1) problem formulation, (2) concept development (of alternatives), (3) detailing (of alternatives' workability), (4) option evaluation, and (5) implementation of chosen plan. Such descriptive stage models line up well with the prescriptive model of process components sketched in Table 2.1.

A special feature of Nutt's (1984) study is the varying operation of three distinct steps within each of the several stages—search, synthesis, and analysis. Using his five stages and three steps-within-stages as a coding scheme, Nutt was able to characterize each of the seventy-three decision processes as belonging to one of five archetypal processes:

1. *Historical model:* Do what has been demonstrated to "work."
2. *Off-the-shelf:* Choose among the best available plans.
3. *Appraisal:* Conduct some kind of decision analysis.
4. *Search:* Look around and wait for a full-blown good idea.
5. *Nova:* Mobilize everything to create an innovative plan.

These categories run fairly parallel to the levels of decision making distinguished in Table 2.3. Apparently, decision makers in organizations do take different approaches—which imply different quality guarantors (see Nutt 1984)—to decision problems of differing nature. A conclusion like this may pave the way toward fruitful utilization of descriptive findings for the design of effective organizational DSMs.

In modern life, of (purely) individual and social decisions the latter seem to be the rule rather than the exception. For professional decision supporters, this observation may be strengthened by the thought that supportable decision problems—the strategic ones calling for explicit analysis (Table 2.2)—are often tackled by several decision makers simultaneously (at least by you and your adviser). Therefore, the development and empirical evaluation of "good" social decision methods seems to be a crucial task for decision theorists who want to aid society in solving its numerous and diverse

decision problems. "No coherent approach exists," says Lindley (1985, p. 180). "Yet the need for one is more urgent now than at any point in the history of the world." We agree.

## CONCLUSIONS, SUGGESTIONS, AND SOME LOOSE ENDS

In this chapter, we have attempted to explicate the idea of decision support, mostly from a decision-theoretic and a cognitive-psychological point of view. Although we have tried to develop our ideas step by step and have covered a lot of ground, we still feel somewhat uneasy. This may have to do with the notion of decision making itself. It seems to be so variable and so task dependent that it is hard to define it usefully in other than a fairly restricted sense (e.g., as applying to choices among gambles). The definition of a decision problem seems general enough that almost any approach toward solving a decision problem could be called a decision support method. Actually, this is a major difficulty in the growing field of (management) decision support systems defined as: "computer-based systems, that help decision makers, confront ill-structured problems, through direct interaction, with data and analysis models" (Sprague & Watson 1989, p. 2; see also Mclean & Sol 1986).

Our own view is that decision making follows a varying mode of cognitive processing, depending on the strategic, tactical or operational nature of the problem (cf. Table 2.2), and that complex decision making consists of information acquisition, problem structuring, and option evaluation (cf. Figure 2.1). Thus, adequate decision support should be specific to the level or mode of decision making, and it may emphasize any one or all three components of Figure 2.1.

There are debates about the value of expert systems vis-à-vis procedural aids for complex decisions (e.g., Fox 1984; Keeney et al. 1988). It would seem that the information acquisition (and storage and retrieval) component of decision support is being captured by expert systems, whereas the problem-structuring and option-evaluation components are incorporated in procedural decision aids. Also, however, expert system designers working with if-then rules are bound to focus on frequently occurring, relatively low-level operational or at most tactical decision problems, on which sufficient experience has been and is being accumulated. In contrast, procedural decision supporters primarily work on complex, strategic decisions where problem structuring and option evaluation are done under a great deal of missing information.

It is a challenge for future research and DS design to integrate substantive (knowledge-based) and procedural decision support such that the DM would not have to operate in a frozen task environment and follow a rigid mode of decision making. The ideas of Miller, Galanter, and Pribram (1960) and of Toda (1976, 1981) are highly relevant here. A recent computer pro-

gram that embodies this kind of integration for multiattribute utility analysis is DECMAK by Bohanec and Rajkovič (1988; see also Rajkovič, Bohanec & Batagelj 1988; Bohanec and Rajkovič, this book).

Designing methods to help people make better decisions than they could do by themselves constitutes the litmus test of decision theory. It appears that this test cannot be administered without the availability of models and modes of "good" decision making, sufficient knowledge about the nature of unaided decision processes, of individuals and in groups and organizations, and a set of practical criteria for evaluating the quality of decisions. In the past, decision theorists and researchers have made gradual progress toward fulfilling these conditions. The task now is to bring normative and descriptive ideas and findings together and to set out on a prescriptive course firmly supported by empirical studies. The application domains are there: in company management, in the educational system, in technology assessment and environmental protection, in medical practice and health care, and perhaps in the judicial system.

## REFERENCES


Adelbratt, T., and H. Montgomery. (1980). Attractiveness and decision rules. *Acta Psychologica, 45,* 177–185.

Anderson, J. R. (1983). *The architecture of cognition.* Cambridge: Harvard University Press.

Arrow, K. J. (1951). *Social choice and individual values.* New York: Wiley.

Bass, B. S. (1983). *Organizational decision making.* Homewood, Ill.: Irwin.

Beach, L. R., and T. R. Mitchell. (1978). A contingency model of the selection of decision strategies. *Academy of Management Review, 3,* 439, 449.

Bezembinder, Th. (1989). Social choice theory and practice. In Ch. Vlek and G. Cvetkovich (eds.), *Social decision methodology for technological projects.* Dordrecht/London/Boston: Kluwer Academic Publishers.

Björkman, M. (1984). Decision making, risk taking, and psychology: Review of empirical findings and psychological theory. *Scandinavian Journal of Psychology, 25,* 31–49.

Blair, D. H., and R. A. Pollak. (1983). Rational collective choice. *Scientific American, 249*(2), 76–83.

Bohanec, M., and V. Rajkovič. (1988). *DECMAK, an expert system shell for multiattribute decision making.* Institute "Jozef Stefan," DP-5031, Lubljana.

———. (this book). Knowledge-based explanation in multiattribute decision making.

Brehmer, B. (1976). Social judgment theory and the analysis of interpersonal conflict. *Psychological Bulletin, 83,* 983–1003.

Christensen-Szalanski, J.J.J. (1978). Problem solving strategies: A selection mechanism, some implications and some data. *Organizational Behavior and Human Performance, 22,* 307–323.

Collingridge, D. (1982). *Critical decision making.* London: Frances Pinter.

Coombs, C. H., R. M. Dawes, and A. Tversky. (1970). *Mathematical psychology: An elementary introduction.* Englewood Cliffs, N.J.: Prentice-Hall.

De Hoog, R. (1983). MIDAS, Sociaal Wetenschappelijke Informatica, Universiteit van Amsterdam.

DeSanctis, G., and R. D. Gallupe. (1987). A foundation for the study of group decision support systems. *Management Science, 33*(5), 589-609.

Edwards, W. (1961). Behavioral decision theory. *Annual Review of Psychology, 12,* 473–498.

Edwards, W., I. Kiss, G. Majone, and M. Toda. (1984). What constitutes "a good decision"? *Acta Psychologica, 56,* 5–27.

Edwards, W., H. Lindman, and L. J. Savage. (1961). Bayesian statistical inference for psychological research. *Psychological Review, 70,* 193–242.

Edwards, W., and W. Newman. (1982). *Multi-attribute evaluation.* London/New York: Sage.

Einhorn, H., and R. M. Hogarth. (1981). Behavioral decision theory: Processes of judgment and choice. *Annual Review of Psychology, 32,* 53–88.

Fischhoff, B., S. Lichentenstein, P. Slovic, S. L. Derby, and R. L. Keeney. (1981). *Acceptable risk.* Cambridge: Cambridge University Press.

Fox, J. (1984). Formal and knowledge-based methods in decision technology. *Acta Psychologica, 56,* 303–331.

Friend, J., and A. Hickling. (1987). *Planning under pressure: The strategic choice approach.* London/New York: Pergamon Press.

Hendrickx, L., Ch. Vlek, and H. Oppewal. Relative importance of scenario information and frequency information in the judgment of risk. *Acta Psychologica* (in press).

Hogarth, R. M. (1987). *Judgment and choice: The psychology of decision.* 2d ed. New York: Wiley.

Humphreys, P., and D. Berkeley. (1984). Handling uncertainty: Levels of analysis of decision problems. In G. Wright (ed.), *Behavioral decision making.* New York/London: Plenum.

Humphreys, P. C., and W. McFadden. (1980). Experiences with MAUD: Aiding decision structuring versus bootstrapping the decision maker. *Acta Psychologica, 45,* 51–69.

Humphreys, P. D., and A. Wisudha. (1982). *MAUD*4. Technical Report 83-5. London: London School of Economics and Political Science, Decision Analysis Unit.

ICRP. (1977). Recommendations of the International Commission on Radiological Protection. *Annals of the ICRP, 1*(3), publ. 26. Oxford: Pergamon.

Janis, I. L. (1972). *Victims of groupthink.* Boston: Houghton Mifflin.

Janis, I. L., and L. Mann. (1977). *Decision making: A psychological analysis of conflict, choice, and commitment.* New York: Free Press.

Johnson, E. J. (1979). *Deciding how to decide: The effort of making a decision.* Technical Report. Chicago: Center for Decision Research, University of Chicago.

Kahneman, D., and A. Tversky. (1982). Variants of certainty. *Cognition, 11,* 143–157.

Keeney, R. L., R. H. Mohring, H. Otway, F. J. Rademacher, and M. M. Richter. (1988). Design aspects of advanced decision support systems. Special issue of *Decision Support Systems, 4*(4), 381–508.

Keeney, R. L., and H. Raiffa. (1976). *Decisions with multiple objectives: Preferences and value trade-offs.* New York: Wiley.

Klieter, G. D. (1975). Dynamic decision behavior: Comments on Rapoport's paper. In D. Wendt and Ch. Vlek (eds.), *Utility, probability and human decision making.* Dordrecht/Boston: Reidel.

Krantz, D. H., R. D. Luce, P. Suppes, and A. Tversky. (1971). *Foundations of measurement.* Vol. 1: *Additive and polynomial representations.* New York: Academic Press.

Larichev, O. I. (1984). Psychological validation of decision methods. *Journal of Applied Systems Analysis, 11,* 37–46.

Lau, J., J. P. Kassirer, and S. G. Pauker. (1983). Decision Maker 3.0: Improved decision analysis by personal computer. *Medical Decision Making, 3,* 39–43.

Lindley, D. V. (1984). *Making decisions.* 2d ed. New York/London: Wiley.

Mclean, E., and H. G. Sol (eds.) (1986). *Decision support systems: A decade in perspective.* Amsterdam: Elsevier/North-Holland.

MacCrimmon, K. R. (1972). Managerial decision making. In J. W. McGuire (ed.), *Contemporary management issues and viewpoints.* Englewood Cliffs, N.J.: Prentice-Hall.

Matheson, J. E., and R. A. Howard. (1968). *An introduction to decision analysis.* Working paper. Menlo Park, Cal.: Stanford Research Institute.

Malhotra, N. K. (1982). Information load and consumer decision making. *Journal of Consumer Research, 8,* 419–430.

Merkhofer, M. W. (1987). *Decision science and social risk management.* Dordrecht: D. Reidel Publishing Company.

Miller, G. A., E. Galanter, and K. H. Pribram. (1960). *Plans and the structure of behavior.* New York: Holt.

Mintzberg, H., D. Raisinghani, and A. Theorêt. (1976). The structure of "unstructured" decision processes. *Administrative Science Quarterly, 21,* 246–275.

Nutt, P. C. (1984). Types of organizational decision processes. *Administrative Science Quarterly, 29,* 414–450.

Olshavsky, R. W. (1979). Task complexity and contingent processing in decision making: A replication and extension. *Organizational Behavior and Human Performance, 24,* 300–316.

Ozernoy, V. M. (1988). Some issues in designing an expert system for multiple criteria decision making. *Acta Psychologica, 68,* 237–253.

Paquette, L., and T. Kida. (1988). The effect of decision strategy and task complexity on decision performance. *Organizational Behavior and Human Decision Processes, 41,* 128–142.

Park, C. W. (1978). A seven-point scale and a decision-maker's simplifying choice strategy: An operationalized satisficing-plus model. *Organizational Behavior and Human Performance, 21,* 252–271.

Payne, J. W. (1976). Task-complexity and contingent processing in decision making: An information search and protocol analysis. *Organizational Behavior and Human Performance, 16,* 366–387.

Payne, J. W. (1982). Contingent decision behavior. *Psychological Bulletin, 92,* 382–402.

Payne, J. W., M. L. Braunstein, and J. S. Carroll. (1978). Exploring predecisional behavior: An alternative approach to decision research. *Organizational Behavior and Human Performance, 22,* 17–44.

Pitz, G. F. (1987). Evaluating decision aiding technologies for genetic counseling. In G. Evers-Kiebooms, J. J. Cassiman, H. van den Berghe and G. d'Ydewalle

(eds.), *Genetic risk, risk perception and decision making.* Birth Defects Original Article Series, *23*(2). New York: A. R. Liss.

Raiffa, H. (1968). *Decision analysis; introductory lectures on choices under uncertainty.* Reading, Mass.: Addison-Wesley.

Rajkovič, V., M. Bohanec, and V. Batagelj. (1988). Knowledge engineering techniques for utility identification. *Acta Psychologica, 68,* 271–286.

Rapoport, A. (1975). Research paradigms for studying dynamic decision behavior. In D. Wendt and Ch. Vlek (eds.), *Utility, probability and human decision making.* Dordrecht/Boston: Reidel.

Reidel, S., and G. F. Pitz. (1986). Utilization-oriented evaluation of decision support systems. *IEEE Transactions on Systems, Man and Cybernetics, 16,* 980–996.

Rohrmann, B., and H. Schutz. (this book). The evaluation of decision aids.

Schachter, R. D. (1986). Evaluating influence diagrams. *Operations Research, 34*(6), 871–882.

Schlaifer, R. (1969). *Analysis of decisions under uncertainty.* New York: McGraw-Hill.

Sen, A. K. (1970). *Collective choice and social welfare.* San Francisco: Holden-Day.

Shugan, S. (1980). The cost of thinking. *Journal of Consumer Research, 7,* 99–111.

Simon, H. (1957). *Administrative behavior: A study of decision-making processes in administrative organization.* 2d ed. New York: Macmillan.

Simon, H. A. (1960). *The new science of management decision.* New York: Harper and Row.

Sjöberg, L. (1980). Volitional problems in carrying through a difficult decision. *Acta Psychologica, 80,* 123–132.

Sonnenberg, F. A., and S. G. Pauker. (1987). *DECISION MAKER 6.0; Operating Manual.* Boston: Division of Clinical Decision-Making, New England Medical Center.

Sprague, R. H., and H. J. Watson. (eds.) (1989). *Decision support systems; putting theory into practice.* 2d ed. Englewood Cliffs, N.J.: Prentice-Hall.

Staw, B. M. (1981). The escalation of commitment to a course of action. *Academy of Management Review, 6,* 577–587.

Svenson, O. (this book). A psychological process perspective on decision making.

Thorngate, W. (1980). Efficient decision heuristics. *Behavioral Science, 25,* 219–225.

Timmermans, D., Ch. Vlek, and L. Hendrickx. (1989). An experimental study of the effectiveness of computer-programmed decision support. In Lockett, A. G. (ed.), *Improving decision making in organizations.* Heidelberg: Springer-Verlag.

Toda, M. (1962). The design of a fungus-eater: A model of human behavior in an unsophisticated environment. *Behavioral Science, 7,* 165–183.

———. (1976). The decision process: A perspective. *International Journal of General Systems, 3,* 79–88.

———. (1980). Emotion and decision making. *Acta Psychologica, 45,* 133–155.

———. (1981). *Man, robot and society; Models and speculations.* The Hague: Martinus Nijhoff.

Tversky, A. (1972). Elimination by aspects: A theory of choice. *Psychological Review, 79,* 281–299.

Tversky, A., and D. Kahneman. (1974). Judgment under uncertainty: Heuristics and biases. *Science, 185,* 1124–1131.

Vlek, Ch., and G. Cvetkovich. (1989). Social decision making on technological

projects: Review of key issues and a recommended procedure. In Ch. Vlek and G. Cvetkovich (eds.), *Social decision methodology for technological projects.* Dordrecht/Boston/London: Kluwer Academic Publishers.

Vlek, Ch., and W. A. Wagenaar. (1979). Judgment and decision under uncertainty. In J. A. Michon, E. G. Eijkman and L.F.W. de Klerk (eds.), *Handbook of Psychonomics.* Vol. 2. Amsterdam: North-Holland.

von Winterfeldt, D. (1980). Structuring decision problems for decision analysis. *Acta Psychologica, 45,* 71–94.

von Winterfeldt, D., and W. Edwards. (1986). *Decision analysis and behavioral research.* Cambridge/New York: Cambridge University Press.

von Winterfeldt, D., and G. W. Fischer. (1975). Multi-attribute utility theory: Models and assessment procedures. In D. Wendt and Ch. Vlek (eds.), *Utility, probability and human decision making.* Dordrecht/Boston: Reidel.

Wisudha, A. (1985). Design of decision aiding systems. In G. Wright (ed.), *Behavioral decision making.* New York: Plenum.

Wright, G. (ed.) (1985). *Behavioral decision making.* New York: Plenum.

# 3

# A Psychological Process Perspective on Decision Making

Ola Svenson

This chapter theorizes about cognitive processes preceding decisions made by single individuals. In doing so, a psychological process tracing perspective (cf. Svenson 1979; Montgomery & Svenson 1989a; Ford et al. 1989; Svenson 1992) will be adopted for presenting evidence and theories for unaided decision making. Readers who want to supplement this perspective with research initiated from other perspectives are referred to other sources, such as Kahneman, Slovic, and Tversky (1982), Abelson and Levi (1985), Arkes and Hammond (1986), von Winterfeldt and Edwards (1986), Rohrmann et al. (1988), Dawes (1988), and Bell, Raiffa, and Tversky (1989a).

The process of making a decision starts with the appearance of a decision problem and the realization of the need for a decision. It continues with the identification and/or construction of decision alternatives, followed by the decision process itself. Because the initial stages are very important for the following decision process, they will also be examined in this chapter. Therefore, in a broader sense, a decision may be defined as a psychological process starting with the realization of the need for a decision, going through the implementation of the decision process, and ending with the registration of the outcome of the decision. The outcome part of a decision is important because it constitutes part of the input for later decisions.

For those active in designing decision support systems, it is important to learn about nonsupported decision processes. This is because any decision support must be compatible with the unaided decision process if any progress is expected. First, compatibility must be achieved for reasons of communication during the decision-aiding process. Second, most decisions reached through decision-aiding techniques are evaluated partly in relation to unaided opinion about the proposed solution of the decision problem.

**TWO TYPES OF DECISIONS**

Most of our lives seem to follow logically from past decisions and present circumstances. A decision problem that appears along this path represents one of two possible generic types of problems. In the first, type A, the decision maker arrives at a point where the future branches into two or more paths, each forming a decision alternative. In this situation, it is not possible to remain at the status quo or even follow the path that seems more natural. The decision maker's task is to choose one of these options, all of which are new alternatives not following more or less automatically from the past. To give a simple illustration, one has to decide on what to eat when in a new restaurant, and often this decision does not follow automatically from the past without any deliberation.

In type B decisions, the decision maker may experience his or her present and projected future situation as unsatisfactory and starts working for a change. In this case, doing nothing to change the situation is one decision alternative (status quo), and possible changes constitute other decision alternatives. A type B decision may also be exemplified by a decision in which the present situation is acceptable but an attractive new alternative emerges (e.g., an attractive job offer). A type B decision often precedes a type A decision. For example, the decision maker may first decide to move to a new place (type B decision), where he or she must choose a new job from a set of alternatives not including his or her earlier profession (type A decision).

In the decision research literature, most decisions are modeled as type A choices among existing choice alternatives (cf. Abelson & Levi 1985). Of course, theoretically, one of the alternatives could be regarded a status quo alternative in the type B case. However, from a psychological point of view, the difference between the two types of decisions should not be ignored, as it may simplify decision theory. First, in a type B situation, the "no action" alternative may function as a reference alternative, which the other alternatives are compared against. Second, the choice of this alternative is often seen as needing fewer psychological resources than other alternatives (fewer transaction costs). Adherence to the already implemented course of action is psychologically a low-cost alternative, which may lead to decision inertia. In other words, one may stick to the old decisions and policy, hoping that it will work out, although it at some level may be perceived as suboptimal (cf. Staw 1976; Staw & Fox 1977; Laughhunn & Payne 1984; Arkes & Blumer 1985; Samuelson & Zeckhauser 1988). Another and related explanation to decision inertia is a reluctance to admit that the decision maker made a suboptimal decision in the past. On the other hand, human life may be seen as a balance between conservatism and a need for change. Therefore, forces counteracting decision inertia may also be activated in many situations. If type A and type B decisions are differentiated, it would be no surprise that they do not activate the same decision processes.

From a psychological perspective, decisions between, for example, generally good alternatives may differ from choices among bad alternatives (Payne, Bettman & Johnson 1988; Tversky & Kahneman 1981; Maule 1989) with different decision rules for different types of decisions. Usually normative decision theory does not allow for this, but decision-aiding techniques somehow have to accommodate for the fact that in some situations decision makers do not want to apply normative decision theory, even if they are informed about how to make rational decisions (Adelbratt & Montgomery 1980).

Few researchers have studied the first stages of a decision process in which the decision maker becomes aware of the need of a decision. This is interesting because the first stages may be decisive for the following choice. Also interesting are the many cases in which people are not aware of when what in retrospect appears as a really important decision was actually made. At the time, the decision was seen as minor, but it may have developed into a major decision through many automatic subdecisions. Detecting or not detecting an important decision problem when it first appears seems to be one of the most fundamental aspects of high-quality decision making. This was illustrated on the societal level by Ingelstam (1980), who analyzed decisions closely knit to industrial complexes (e.g., the traffic road automobile industrial complex and the energy-industrial complex). According to Ingelstam, "important societal decisions no longer present themselves in a clear-cut way. . . . They do not present themselves *at all*" (p. 266). Janis and Mann (1977) presented a model in which the first stage in the decision process was the realization of the need of change. In an empirical study, Karlsson (1987) found that a majority of the important real-life decisions reported by his subjects were of type B and standard situations (type A), with several alternatives in minority.

## CREATING DECISION ALTERNATIVES

Once a decision problem has been heeded, this does not mean that all available options follow automatically. In type A situations, it is clear that several alternatives exist, but in type B situations no decision alternative except the status quo in the form of an extrapolation from the present can be assumed.

Even if there are several alternatives, those existing are sometimes ill defined, and additional alternatives may have to be created. The initial formulation of a decision problem is assumed to be very important for the final decision. First, the construction and early scanning of decision alternatives are significantly related to the final decision (Montgomery & Svenson 1989b). In deciding what move to make in chess, good players differ from weak ones in terms of generation of alternatives because they have already included the finally chosen move in the first set of alternatives (de Groot

1965). Second, the way in which formally equal alternatives are described may be decisive for the final choice. The striking effect of "framing" illustrates this very convincingly (cf. Tversky & Kahneman 1981). Here, Montgomery and Svenson (1989a, p. 130), distinguish between objective and subjective framing, of which the latter experienced context is effective in producing widely diverging decisions across subjects and across formally equal decision problems. Decision alternatives appear in space and time. For the decision maker, alternatives may phenomenologically seem like scenarios or casual chains of events into the future (Axelrod 1976; Abelson 1981; Schoemaker 1988). Even quite abstract numerical laboratory tasks may be elaborated by the subjects, who may add hypothetical future developments to quite abstract options. This may be done to make the task more concrete and real (Svenson 1985).

All the possible contingencies of a decision tree are not explored by the decision maker. Because of cognitive limitations, individuals are more likely to explore a few of the possible paths through a decision tree while constructing and exploring decision alternatives. Decision theory projects the future onto the present, sometimes with explicit discounting of value (Fishburn 1970), when describing alternatives. People must do the same sometimes, but the time dimension may be simply neglected or be explicit for some alternatives only.

In this chapter, decision alternatives are represented in the following way for both type A and type B decisions. An *alternative* (e.g., a trip) is characterized by different *attributes* (e.g., cost, temperature at the destination). Alternatives are characterized by physical or objective characteristics (e.g., cost in SEK, temperature, size of hotel room) having a subjective correspondence in perceived *aspects* (e.g., perceived size of room). When making a decision, those aspects are given subjective values on scales of attractiveness, one for each of the attributes. This representation of the alternatives constitutes the psychological decision problem space. A *value system* is a common concept for those principles used for ordering the aspects on an attribute in a preference order. Montgomery (1989) provides a recent discussion of values in decision making, as do Bell, Raiffa, and Tversky (1989).

My definition of a decision problem is in general accordance with decision theory's dimensional representation (Keeney & Raiffa 1976; von Winterfeldt & Edwards 1986). However, in contrast to most other decision theoretic representations, it does not assume commensurability of attractiveness across attributes or more than an a priori rank order representation of attractiveness of the aspects within an attribute (Svenson 1979). Like most other decision theoretic representations, this approach has difficulties in representing decision alternatives perceived in other and more holistic ways. For example, a piece of art or another individual may give holistic impressions that are not well suited for dimensional atomistic or feature analysis. Still, the repre-

sentation seems well suited for forming the link between decision theory and more purely descriptive psychological representations of decision problems.

## THREE DESCRIPTIVE MODELS OF DECISION MAKING

Descriptive process models of decision making include models in which the decision maker applies a set of decision rules to the alternatives to choose from (Montgomery & Svenson 1976; Payne 1976, 1982; Svenson 1979). More recent process models (Montgomery 1983; Montgomery & Svenson 1989a) also include changes in the evaluative representation of the decision alternatives during the entire decision process. This continuously ongoing restructuring of a decision problem may be driven by goals such as a wish to reach a decision with a minimum of conflict or to reach a decision that can be justified for one's self and others. One particular structure of a decision problem, that of dominance, meets several psychological requirements of an acceptable decision. In several investigations, it has been shown that cognitive processes in decision making are compatible with a search for dominance model (Montgomery & Svenson 1989a). This has been illustrated through subjects' information search and restructuring of alternatives during the decision process so that the chosen alternative comes closer to dominating its most serious competitor toward the end of a decision process than it was at the beginning (Montgomery & Svenson 1989b; Dahlstrand & Montgomery 1989). Other recent formulations (Beach & Mitchell 1967) have focused on representations of decision alternatives, which are similar to scripts or scenarios.

### The Dominance Search Model

Decisions are easy to make when one alternative dominates the other(s)—that is, when it is equal or better on all attributes and better on at least one attribute than its competitor(s). Montgomery (1983) focused on this in his dominance search model of decision making. The most important aspect of this model is that it describes the decision maker as changing his or her representation of a problem during the process of making a decision. More specifically, the decision maker's evaluation of the chosen alternative is modified in such a way that it appears to be closer to dominating its most serious competitor toward the end of the decision process.

The model contains four main phases. In the first, the *preediting phase,* the decision maker selects alternatives and attributes to consider in the decision process. This phase is related but not identical to the editing described by Kahneman and Tversky (1979). This phase is also related to the creation of the decision alternatives stage described earlier. However, the creation of alternatives stage does not presuppose an attribute $x$ alternative representa-

tion. And it is not as closely tied to the final representation of the decision alternatives as in the preediting phase of the dominance search model.

The second phase according to Montgomery concerns *finding a promising alternative*. Here, one alternative is picked out that seems to have a chance of becoming dominant over the others. The reasons for this may be either evident or unclear to the decision maker.

After this, *the dominance testing phase* follows. The promising alternative is tested against the others to see if it dominates the other alternatives. If this is not the case, the fourth phase, the *dominance structuring phase,* starts. Now the decision maker tries to change the decision problem in various ways to achieve dominance. Put in decision support terminology, the decision maker performs a sensitivity analysis on his or her attractiveness representation, but the analysis is made with a specific purpose: to find out whether a decision under dominance can be structured so that the promising alternative stays within the acceptable uncertainty bounds of the decision maker's mental representation of the situation.

### Image Theory

Like most process tracing decision research, image theory was presented in response to doubts about the descriptive competence of behavioral decision theory. Beach and Mitchell (1988) recently published the main theoretical framework for this descriptive model of decision making.

In image theory, traditional multiattribute representations are substituted for broader concepts. Images are cognitive representations or schemata claimed to be specific to decision behavior. An image represents the decision maker's ideals or principles in some field of decision making. It also includes goals and what to do to reach those goals in that particular field of decision making. To specify, decisions are seen as the result of the utilization of four different images.

First, the *self-image* represents the decision maker's basic values, morals, and behavioral codes—principles regarded as desirable without much further thought. Second, the *trajectory image* represents the decision maker's immediate and remote goals temporally ordered and forming a plan for the future. New goals may be included in this image through evaluation against the self-image and the current trajectory image. Third, the *action image* represents the different action plans implemented for reaching the goals on the trajectory image. Fourth, the *projected image* consists of events and states that the decision maker predicts what will follow if the current action plan is carried out.

It is clear that this represents a different modeling of decision-making processes than those usually employed. In principle, however, it seems possible to model much of the above in a carefully chosen multiattribute model. But in contrast with multiattribute decision theory, a decision process also

includes the adoption or rejection of goals, as well as contingent evaluation of current progress (which perhaps could be related to control theory). The reevaluation of current goals is similar to some of the thoughts of other models of decision making (cf. Svenson 1992; Montgomery 1983; Montgomery & Svenson 1989a).

Although image theory has not been explicitly presented as a process model, it has characteristics that place it in that category (e.g., the continuous monitoring of the projected image so that it does not deviate too much from the trajectory image). The model seems not yet elaborate enough to provide a full-blown alternative in itself. Still, it contains many interesting ideas that might both complicate and enrich the design of decision-aiding software.

### Differentiation and Consolidation Theory

Recently Svenson (1992) presented the differentiation and consolidation theory of decision-making, which models human decision making as an active process in which one alternative is gradually differentiated from other available alternatives. The theory is based on the assumption that it is not sufficient to choose the best alternative, but that a decision involves the selection and creation of a candidate that is sufficiently superior for a decision. This is achieved in differentiation processes that are holistic, structural or process related. To exemplify, structural differentiation includes both facts and attractiveness restructuring.

Following a decision, the theory predicts consolidation processes that work in favor of the chosen alternative. Both differentiation and consolidation are driven by the fact that through experience with the impredictability of the future, a decision maker has learned to prepare for threats against the chosen alternative. The further this alternative has been differentiated and consolidated, the less the risk of post-decision ambiguity, regret or decision reversal.

Empirical evidence for the theory has been published by Svenson and Malmsten (1991) and Svenson and Benthorn (1992). Differentiation and consolidation theory includes many other decision theories that may be regarded as special cases if they are further developed to fit the framework provided by the new theory.

## LEVELS OF EXPLORATION OF VALUES AND DECISION PROCESSES

Decisions are based on the decision maker's values, which are mapped onto the decision problem. The extent of the depth of the search and processing of values differ as a result of, for example, earlier experience that the decision maker may have of a particular situation and its perceived im-

portance. The following distinctions are related to how a decision situation is apprehended and to how much in depth a decision maker explores his or her own value system in order to reach a decision. At the lowest level (1), no explicit mapping of the value system onto the decision problem is performed, while at the highest level (4), elaborate mapping of values and a creative process involving structuring and restructuring of the problem precede the decision. The borders between the different levels of processing for a decision are not as sharp as the identification of the four levels seems to indicate. Rather, the levels indicate different approximate intervals on a continuum from no to a high degree of information processing for mapping the decision maker's values onto the decision problem he or she is about to solve.

### Level 1 Decisions

At the first level, the decision maker recognizes the situation as similar to an earlier one. He or she does not refer to any values at all, although the decision strategy may be traced back to a value system that determined the decision the first time it was made. This is because it is possible to use, for example, earlier successful decisions as reference alternatives, which then represent a positive value. In this way, no explicit reference to the decision maker's value system is needed.

Decisions on the first level include processes other than comparisons of values. Processes such as similarity matches between current alternatives and alternatives chosen in the past dominate the psychological information processes. The alternative most similar to an earlier successful decision alternative is chosen without any reference to values in the comparison process. Alternatives that are similar to earlier nonchosen alternatives or unsuccessful decisions may also be eliminated without any reference to any values at the moment. Another type of decision on this level is represented by decisions conforming to a trusted other. That is, the decision maker makes the same choice as somebody whom he or she trusts and who holds the same values. Such decisions may be made following the trusted other's real decisions, or the decision maker may imagine what the trusted other would decide if she or he was in the same situation.

Level 1 decisions lead to a final choice in many situations, but they may also be seen as a first stage in a more complex decision process. In the latter case, this type of decision may produce promising or reference alternatives used in later stages of, for example, a dominance structuring process. Such alternatives are important also in more elaborate decision processes.

Exemplifying a decision on level 1, the decision of what car to buy may be determined by an earlier decision. The reasoning and justification may be as follows: "When my old car finally broke down completely, I decided to buy a new Volvo because it is most similar to the old Volvo I had for years."

### Level 2 Decisions

At this level the decision maker feels that he or she makes a decision with reference to preferences on one or a few attributes. While at the first level no reference is made to evaluation, the second level also involves a routine evaluation of the aspects with reference to how the attributes are generally valued. To exemplify, the evaluation that a low price is good is used, as well as the higher attractiveness of a bigger size package in the supermarket. In the case of the decision to buy a car, it could be an Oldsmobile (because it is the biggest available) in one situation and the closest available Japanese car (because it is most reliable) in another situation with another decision maker. Note that decision processes at a given level also include lower-level processes.

Decisions at the second level represent stereotypical and static mappings on existing valuations of the manifest aspects on attributes characterizing the alternatives (e.g., "biggest is best"). This is done without any further explorations into why those values are held. At this level, no new trade-offs between attributes may be performed. No explicit conflicts are present. Decisions are based on one or perhaps a few salient attributes jointly favoring one alternative. Noncompensatory decision rules determine level 2 decisions. Only earlier formed stereotyped trade-offs may be executed in reaching a decision. In order to get along in life, it seems necessary that most frequent decisions involve only level 1 and level 2 processing.

Another type of level 2 decisions are those in which some very quick emotional or motivational process determines a decision (or the promising alternative for a higher level decision). Zajonc (1980) has discussed such decisions based on feelings rather than cognitive inferences.

### Level 3 Decisions

At this level, there exists a nonautomatic correspondence between the decision maker's value system and the aspects describing the decision alternatives. Instead of just stating to themselves, "The more of this attribute, the better," decision makers try to relate attributes to their own value systems. Decisions at this level may also use trade-offs between the attractiveness of aspects on different attributes or transformations of attributes into new ones (e.g., cost per square meter replaces the two constituents). Note, however, that no new decision alternatives are created in processing at level 3. To exemplify, a decision at this level may be motivated through "I decide to buy this car over that car because I find the difference in price is not so important and I value its superior driving characteristics so much that they outweigh its poorer exterior looks." All of the level 3 processing presupposes access to values that may be regarded as meta-values to the value system used for levels 1 and 2 decisions. Active dominance structuring may be found at this level of decision making and higher.

Most of this chapter (and this book) concerns decisions made at level 3 or higher. When decisions are made at the first two levels, the decision maker sees no apparent need for decision-aiding techniques. Note, however, how important it may be, for example, in business or in politics, to realize when it is not sufficient to work at levels 1 and 2 because simple decisions may lead to complex consequences.

### Level 4 Decisions

At the fourth level, the decision maker faces a new and unfamiliar decision problem in which the alternatives have to be elicited or created. The decision maker now goes beyond the immediate present in terms of values and facts. Concerning facts, the decision maker may extrapolate and elaborate the alternatives presented and/or create totally new ones. Here, decision theory connects to the psychology of problem solving because parts of the constructed decision alternatives may be derived in problem-solving processes. For example, different possible ways of attaining a specific goal (to get a better car, say) may involve solving the problem of how to make the old car perform better (one alternative) and selecting criteria for the selection of an alternative used car (to buy). Future scenarios like those presented, for example, in image theory and other elaborations of the decision problem may also occur at this level. Concerning values, the decision maker actively relates the present to his or her value system when creating new alternatives, testing their realism, and determining their attractiveness.

Most people use all four levels of decision making. Some may be engaged in level 4 decision making less often than others. Montgomery (in press) distinguished between simplification and elaboration in decision making that may be related to level 2 versus levels 3 and 4 decisions. Again, it is important to note that, as a rule, lower-level processes are also included as subprocesses in higher-level processing.

The more frequent, well learned, and routinized a decision is, the further down the hierarchy it is likely to be pushed. This is because decisions lower in the hierarchy are associated with less cognitive effort. Hence, energetic resources may be reallocated from former, more demanding decisions.

Type A decisions, in which a choice between a set of decision alternatives emerging in front of the decision maker, may involve those from all levels, including level 4 (in which new alternatives and new mappings of basic values on the current problem may have to be performed). What the decision maker perceives as more important decisions may be assumed to require higher-level processing in both type A and type B situations. If an important decision is made at, say, level 2, it may be harder to face and justify the consequences if they turn out unfavorably.

Because type B decisions involve considerations or decisions to leave the natural extrapolation of the past, such decisions may or may not involve

higher-level processing. However, at least level 2 processing is needed in type B decisions, and as the decisions become more important and involving, level 3 or 4 processing is likely to occur.

Lack of resources, for example, induced by time pressure, is assumed to favor level 1 and level 2 decision making. This is corroborated by findings that time pressure leads to greater popularity of noncompensatory decision rules than compensatory rules (cf. Christensen-Szalanski 1980; Billings & Marcus 1983). However, under even at least moderate time pressure, more cognitive resources may be mobilized if the decisions are important, and the processing may therefore be performed at the same or even at a higher level than usually (Wallsten & Barton 1982).

The levels of processing may be compared to the cognitive control issue and the repeated versus unique decision distinction. To exemplify, Rasmussen's skill-, rule-, and knowledge-based classification of control behavior (cf. Rasmussen, Duncan & Le Plat 1987) may be compared to the present levels if it is assumed that consulting one's value system requires mental effort and that therefore less effort-demanding routines are developed for pushing the processing of repeated similar decisions down to lower levels.

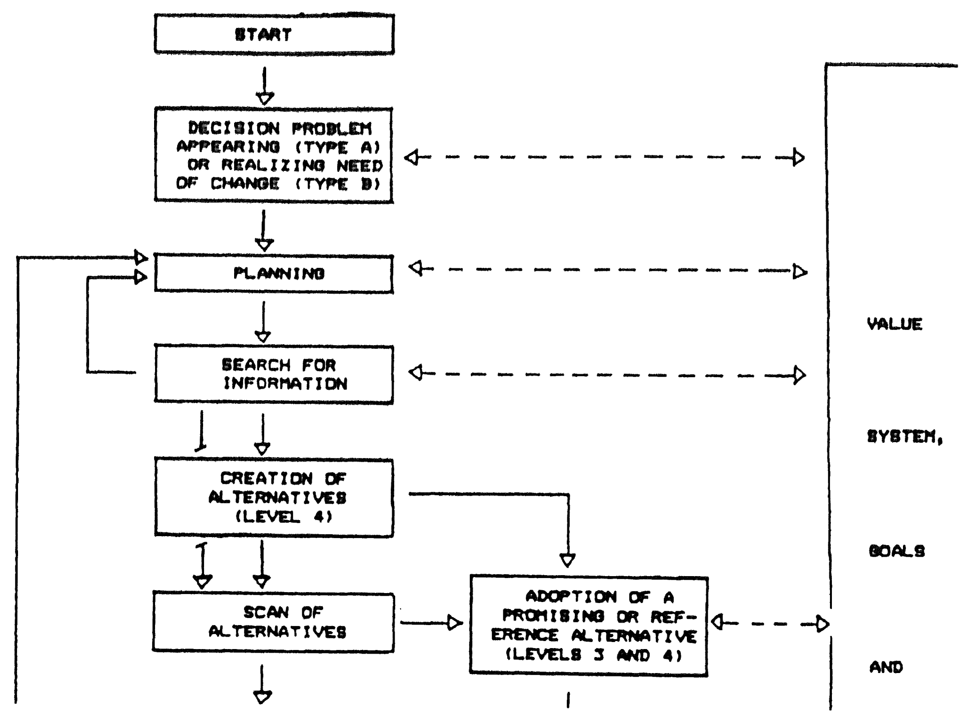
## A PROCESS MODEL OF INDIVIDUAL DECISION MAKING

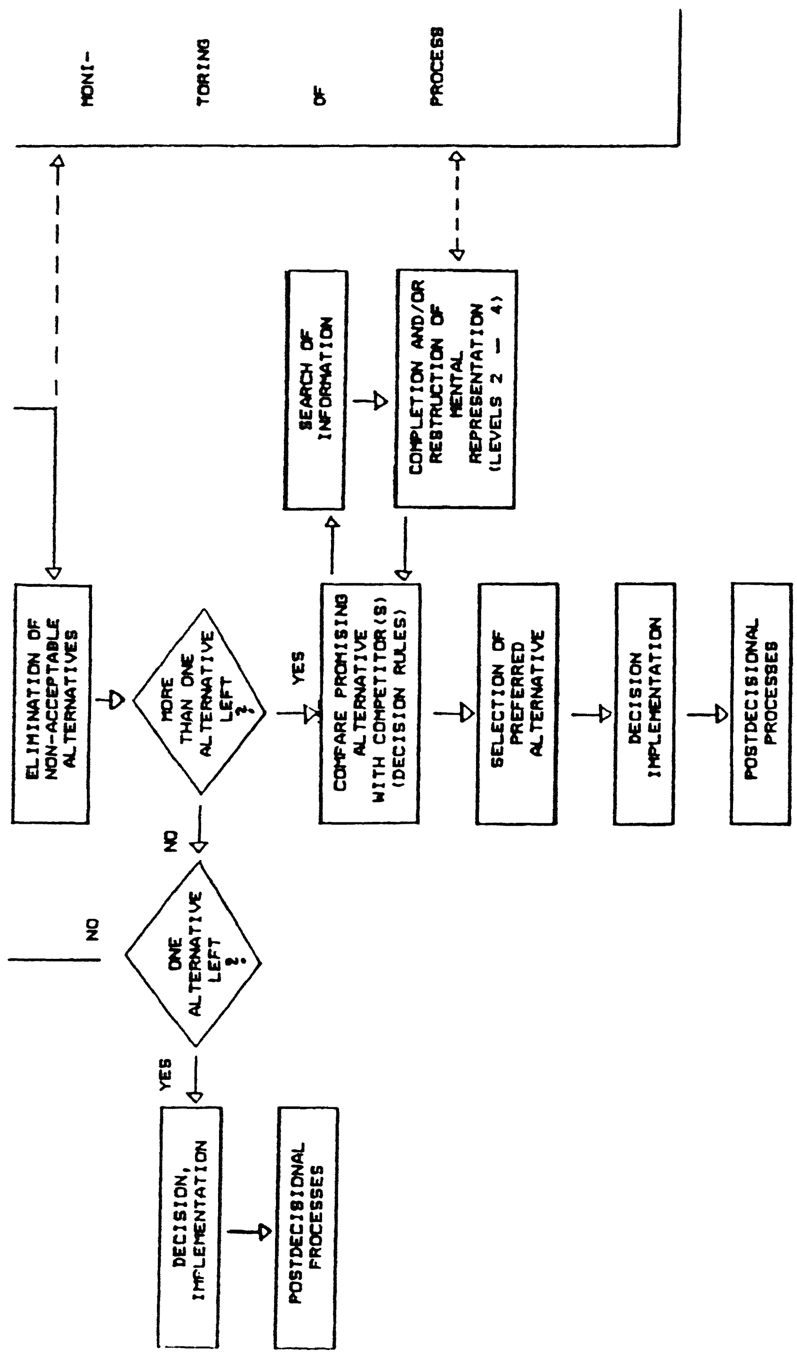
The process model presented here contains all levels of decision making. Specifically, it elaborates level 4 and 3 decision processes because such decisions are considered more interesting in a decision-aiding context and because they are fundamental to lower-level routinized decisions. For example, many level 1 and 2 decisions are replications of the decision maker's own or others' decisions which in the beginning were treated as decisions at more complex levels.

Figure 3.1 presents a flowchart illustrating the main stages of a decision process. The process starts at the top and ends with a decision. To the far right in the figure, the vertically extended box represents the decision maker's value system for mappings of the current problem and a monitoring system storing the meta-level strategies governing the decision process. Consultations of this function may take place at almost any stage of the decision process, as indicated by the dashed lines. The value system contains both more intellectual values (e.g., norms and cultural values) and more fundamental physiologically, emotionally, and socially related values (associated with e.g., food, sex, or security). The value system may be spontaneously and automatically activated (Zajonc 1980) or more deliberately consulted.

Following the start of the process, the decision maker may face a type A (several options emerging at the same time) or a type B decision (realizing the need of change and creating or observing alternatives branching away from the doing nothing alternative). In both cases, planning of how to conduct the decision process will follow.

**Figure 3.1**
**A Process Model of Decision Making**




MONI-
TORING
OF
PROCESS
SEARCH OF
INFORMATION
COMPLETION AND/OR
RESTRUCTION OF
MENTAL
REPRESENTATION
(LEVELS 2 — 4)
ELIMINATION OF
NON-ACCEPTABLE
ALTERNATIVES
MORE
THAN ONE
ALTERNATIVE
LEFT
?
YES
COMPARE PROMISING
ALTERNATIVE
WITH COMPETITOR(S)
(DECISION RULES)
SELECTION OF
PREFERRED
ALTERNATIVE
DECISION
IMPLEMENTATION
POSTDECISIONAL
PROCESSES
NO
NO
ONE
ALTERNATIVE
LEFT
?
YES
DECISION,
IMPLEMENTATION
POSTDECISIONAL
PROCESSES

*Planning* may be explicit or implicit and unconscious and includes determining the level at which a decision should be made, the goals to be attained in the situation, and the strategy for reaching those goals. All of these components of planning are interrelated and determine in part what decision rules and restructuring will be used in the processing of the information about the decision alternatives.

The level at which a decision problem is addressed may be determined by such factors as experience with the situation, judged importance, difficulty of situation, and resources available. However, the classification of a decision problem should not be regarded as invariably fixed. Instead, it may be continuously changing because decisions are made in a changing world and because the process of solving a decision problem involves continuous restructuring and reappraisal, both before and after the decision has been made (Montgomery & Svenson 1989a; Festinger 1964; Lawler et al. 1975). To a great extent, decision making is a process contingent on the particular information just processed (Payne 1982) but within the general frames provided by the value system and the goals evoked before a particular problem was presented.

*Search for information* follows planning. As the arrow going back to planning indicates, the way in which search is performed also depends on how the information is displayed. When, for example, the information is organized either by attribute (e.g., price for all products first) or alternative (e.g., one purchase offer at a time), subjects sometimes change their processing accordingly (Bettman & Kakkar 1977; Herstein 1981) and sometimes they do not (Sundstroem 1989). One important difference between the former and latter studies was that the information was available all the time and could be reinvestigated at any time in the former studies but only once, when first acquired, in the latter. In conclusion, when the information has to be memorized, the presentation format seems to affect the information search pattern less than when the information is available all the time.

The *creation of alternatives* is an important aspect of decision-aiding techniques but takes place for level 4 unaided decisions only. Actually, most decision-aiding techniques should regard a decision problem as a situation in which new alternatives are first created. Even if this is done just for immediate rejection, it gives a firmer anchoring in both reality and in the person's value system, which is advantageous for reaching the final decision. A *reference alternative* may sometimes be identical with the *promising alternative* already presented in conjunction with the dominance search model. The reference alternative functions as an evaluative anchor in the mind of the decision maker, and it may be abstract or concrete. An *abstract reference alternative* consists of a set of limiting aspects on a set of attributes. A set of aspiration levels (Tietz 1983; Lopes 1987) illustrates this because the decision maker knows what he or she wants on the different attributes but has no concrete gestalt of such an alternative. While an abstract reference alternative is based on evaluations of attributes, a *concrete reference alternative* is

based on an existing or imagined alternative forming a gestalt in itself. Recently, Bell, Raiffa, and Tversky (1989b) pointed out the importance of reference alternatives and some consequences for decision-aiding techniques not only for level 4 decisions. Here, more or less complete scenarios or mental representations like those handled by image theory may be applicable as descriptions of the reference alternative in addition to aspect times attribute representations. When comparisons are made for eliminations or in tests of the promising alternative (later in the flowchart), the reference alternative may be consulted, the levels on the specific attributes read off and compared to another alternative. Montgomery (1989) discusses anchoring in decision processes and refers to specific levels on different attributes. Those levels are used in dominance structuring using positive or negative evaluations relative to the anchors.

A concrete reference alternative may also be chosen among the alternatives attainable and present in the decision situation. The reference alternative may later serve the function of a measuring tool for sorting the remaining alternatives into possibly preferred and unacceptable options. The importance of a reference alternative was illustrated by Tyszka (1983) and Payne (1982), who showed that among two equally valued alternatives, introduction of a third reference alternative that was dominated by just one alternative of the first pair resulted in the choice of the nondominated alternative. A promising alternative (Montgomery 1983; Montgomery & Svenson 1989b) may be adopted following *scanning* among the immediately available alternatives, or it may be created and after that incorporated into the set of decision alternatives.

The *elimination* of nonacceptable alternatives is a cognitively important process because it reduces the set of alternatives and saves cognitive effort so that energetic resources may be allocated to the processing of the remaining alternatives. To exemplify, the use of the conjunctive (Svenson 1979) or satisficing rule (Simon 1955) leads to the rejection of all alternatives with aspects below certain criteria on the different attributes. Elimination may also be performed through, for example, a disjunctive decision rule, which prescribes that an alternative is selected (to the pool of alternatives to be considered further) by a single valuable aspect exceeding a criterion value on that attribute. Alternatives not selected in this way are not considered any further in the decision process.

If all alternatives are eliminated, then reappraisal of values and decision alternatives must follow if the decision maker is ever going to make a decision. If there is only one alternative left, this alternative will be the final choice (exit to the left in Figure 3.1). If two or more alternatives remain, *comparison* follows. Although more than two alternatives may remain in this stage, most of the cognitive effort is often concentrated on the promising alternative and its most serious competitor (Montgomery & Svenson 1989b; Dahlstrand & Montgomery 1989).

*Completion and/or restructuring* of the mental representation is done in

response to the requirements arising from a misfit between the goal of a decision process (to find a dominating alternative, an alternative that may be justified for oneself and others, an alternative that fulfills just one criterion such as being the cheapest, an alternative most similar to what a significant other would choose, an alternative with the greatest emotional appeal, an alternative favored by as many arguments as possible, and so forth) and the actual situation. Montgomery (1983) exemplifies restructuring with dominance structuring, and completion of information is exemplified by Aschenbrenner, Albert, and Schmalhofer (1984), who found that information was searched until the summed cumulative difference in attractiveness between two alternatives exceeded a given number. Notice that reappraisals of the value system leading to restructuring of facts and of mappings of values in conjunction with information search may be quite urgent at this point in order to arrive at a final decision.

When a mental representation has been achieved, which permits the application of one or more effective decision rules, the *preferred alternative* may finally be selected and the *decision announced* and *implemented.* It is interesting to note that the preferred alternative sometimes may be predicted quite early in the decision process (Montgomery & Svenson 1989b), which means that the initially promising alternative has a higher chance of being finally selected than its competitors.

*Postdecisional processes* have interested few researchers, and yet it is important to know about them. In fact, most of our decisions about the future are discussed or investigated postdecisional processes in terms of changing values (Festinger 1964; Janis & Mann 1977) and memories of facts (Fischhoff 1975).

## CONCLUDING REMARKS

Decision aiding should heighten the sensitivity of decision makers, enabling them to detect in time when there is a decision problem. A decision maker monitors a continuous stream of events and actions, most of which seem to follow naturally and almost automatically from past decisions. However, in a dynamic world, it is important to realize when a new decision has to be made. Otherwise, changing conditions and external forces will gradually start making decisions by themselves. If a decision problem is not detected in time, reversals of already started developments may have to be part of a decision when it is finally made. A decision maker who is late in detecting such creeping developments faces fewer but more difficult decision problems than the more alert decision maker. Relating to the framework of this chapter, detection of levels 1 and 2 decisions in need of processing at higher levels should be part of any decision-aiding technique. Decision aiding is made for the future. Therefore, it is important to remember that such techniques should prepare the decision maker for future developments be-

yond the immediately perceived consequences and inform him or her about signs in the future that may appear, indicating the need for a new decision.

The creation of decision alternatives may be hampered by an initially promising option which has been shown to have a psychological advantage over its competitors. One of the powers of decision-aiding tools is to keep alternatives eliminated early in the process alive for later reappraisal, which may not have happened in unaided decision making.

In decision aiding, it is important to elicit factual scenarios of what might follow different decisions, but it is also important to allow for and expose the uncertainty of values, which is inherent in all decision making (Fischhoff, Slovic & Lichtenstein 1980). This concerns not only conflicting goals derived from the same value system. It also refers to the fact that one does not always know what values apply on level 3 and 4 decision problems. As illustrated by the dominance search model, decision makers actively use their own uncertainty of values in the restructuring of a problem in order to facilitate a decision. This is partly reflected in the decision-analysis method presented by Moskowitz, Wong and Chu (1989).

Decision-aiding techniques often provide a structuring of a decision problem in such a way that computer algorithms (after necessary parameter selection) may be applied in solving the problem. The human decision maker has a more flexible approach to decision making than a computer program. The human decision maker uses different decision rules in different situations. In order to approach the human decision process and thereby gain increased credibility, decision-aiding techniques might profit from incorporating a wider set of decision rules. In addition, a relatively limited set of alternative decision rules may improve the trustworthiness of decision-aiding techniques significantly. Such decision-aiding techniques would sometimes violate one of the trademarks of decision-aiding tools, consistency. This is because some decision rules, all reasonable in isolation, give inconsistent results when applied to the same set of alternatives. It would then be up to the decision maker to choose, on a meta level, the representation of a decision problem and the decision rule or rules he or she finds most applicable in each situation. Still, a good decision aid would offer information about inconsistencies to the decision maker and provide advice about how to solve them through proper representation of the decision problem and application of a consistent set of decision rules.

## REFERENCES

Abelson, R. P. (1981). Psychological status of the script concept. *American Psychologist, 36,* 715–729.

Abelson, R. P., and A. Levi. (1985). Decision making and decision theory. In G. Lindzey and E. Aronson (eds.), *Handbook of social psychology,* vol. 1. Hillside, N.J.: Erlbaum.

Adelbratt, T., and H. Montgomery. (1980). Attractiveness of decision rules. *Acta Psychologica, 45,* 177–185.

Arkes, H. R., and C. Blumer. (1985). The psychology of sunk cost. *Organizational Behavior and Human Decision Processes, 35,* 124–140.

Arkes, H. R., and K. R. Hammond. (eds.) (1986). *Judgment and decision making.* Cambridge: Cambridge University Press.

Aschenbrenner, K. M., D. Albert, and F. Schmalhofer. (1984). Stochastic choice hennistics. *Acta Psychologica, 45,* 7–34.

Axelrod, P. (ed.) (1976). *Structure of decision: The cognitive maps of political elites.* Princeton: Princeton University Press.

Beach, L. R., and T. R. Mitchell. (1987). Image theory: Principles, goals and plans in decision making. *Acta Psychologica, 66,* 201–220.

Bell, D. E., H. Raiffa, and A. Tversky. (eds.). (1989a). *Decision making: Descriptive, normative and prescriptive interactions.* Cambridge: Cambridge University Press.

———. (1989b). Descriptive, normative and prescriptive interactions in decision making. In D. E. Bell, H. Raiffa and A. Tversky (eds.), *Decision making: Descriptive, normative and prescriptive interactions.* Cambridge: Cambridge University Press.

Bettman, J. R., and P. Kakkar. (1977). Effects on information presentation format on consumer information acquisition strategies. *Journal of Consumer Research, 3,* 233–240.

Billings, R. S., and S. A. Marcus. (1983). Measures of compensatory and noncompensatory models of decision behavior: Process tracing versus policy capturing. *Organizational Behavior and Human Performance, 22,* 307–323.

Christensen-Szalanski, J. J. (1980). A further examination of the selection of problem solving strategies: The effect of deadlines and analytic aptitudes. *Organizational Behavior and Human Performance, 25,* 107–122.

Dahlstrand, U., and H. Montgomery. (1989). Information search and evaluative processes in decision making: A computer-based process-tracing study. In H. Montgomery and O. Svenson (eds.), *Process and structure in human decision making.* Chichester: Wiley.

Dawes, R. M. (1988). *Rational choice in an uncertain world.* New York: Harcourt Brace Jovanovich.

Festinger, L. (1964). *Conflict, decision and dissonance.* Stanford: Stanford University Press.

Fishburn, P. C. (1970). *Utility theory for decision making.* New York: Wiley.

Fischhoff, B. (1975). Hindsight is not equal to foresight: The effect of outcome knowledge on judgments under uncertainty. *Journal of Experimental Psychology: HPP, 1,* 288–299.

Fischhoff, B., P. Slovic, and S. Lichtenstein. (1980). Knowing what you want: Measuring labile values. In T. S. Wallsten (ed.), *Cognitive processes in choice and decision behavior.* Hillside, N.J.: Erlbaum.

Ford, J. K., N. Schmitt, S. L. Schechtman, B. M. Hults, and M. L. Doherty. (1989). Process tracing methods: Contributions, problems and neglected research questions. *Organizational Behavior and Human Decision Processes, 43,* 75–117.

de Groot, A. D. (1965). *Thought and choice in chess.* The Hague: Mouton.

Herstein, J. A. (1981). Keep the voter's limit in mind: A cognitive processing analysis

of decision making in voting. *Journal of Personality and Social Psychology, 40,* 843–861.

Ingelstam, L. (1980). Decision making and strategic social planning. *Acta Psychologica, 45,* 265–271.

Janis, I. L., and L. Mann. (1977). *Decision making.* New York: Free Press.

Kahneman, D., P. Slovic, and A. Tversky. (eds.) (1982). *Judgment under uncertainty: Heuristics and biases.* Cambridge: Cambridge University Press.

Kahneman, D., and A. Tversky. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, 47,* 263–291.

Karlsson, G. (1987). *A phenomenological psychological study of the experience of making a decision: Theoretical foundation and empirical applications in the field of decision making and choice.* Stockholm: Akademitryck.

Keeney, R. L., and H. Raiffa. (1976). *Decisions with multiple objectives: Preferences and value tradeoffs.* New York: Wiley.

Laughhunn, D., and J. W. Payne. (1984). The impact of sunk outcomes on risky choice behavior. *Canadian Journal of Information Processing and Operational Research, 22,* 155–181.

Lawler, E. E., W. J. Kuleck, J. S. Rhode, and S. E. Sorensen. (1975). Job choice and post decision dissonance. *Organizational Behavior and Human Performance, 13,* 133–145.

Lopes, L. L. (1987). Between hope and fear: The psychology of risk. *Advance in Experimental Social Psychology, 20,* 255–295.

Maule, J. A. (1989). Positive and negative decision-frames: A verbal protocol analysis of the Asian disease problem of Tversky and Kahneman. In H. Montgomery and O. Svenson (eds.), *Process and structure in human decision making.* Chichester: Wiley.

Montgomery, H. (1983). Decision rules and the search for a dominance structure: Towards a process model of decision making. In P. Humphreys, O. Svenson and A. Vari (eds.), *Analyzing and aiding decision processes.* Amsterdam: North-Holland.

———. (1989). From cognition to action: The search for dominance in decision making. In H. Montgomery & O. Svenson (eds.), *Process and structure in human decision making.* Chichester: Wiley.

———. (in press). The search for a dominance structure: Simplification and elaboration in decision making. In D. Vickens and P. L. Smith (eds.), *Human information processing: Measures, mechanisms and models.* Amsterdam: North-Holland.

Montgomery, H., and O. Svenson. (1976). On decision rules and information processing strategies for choices among multiattribute alternatives. *Scandinavian Journal of Psychology, 17,* 283–291.

———. (1989a). *Process and structure in human decision making.* Chichester: Wiley.

———. (1989b). A think-aloud study of dominance structuring in decision processes. In H. Montgomery & O. Svenson (eds.), *Process and structure in human decision making.* Chichester: Wiley.

Moskowitz, H., R. T. Wong, and P. Y. Chu. (1989). Robust interactive decision analysis (RID): Behavioral results and implications. *Journal of Behavioral Decision Making, 2,* 95–111.

Payne, J. W. (1976). Task complexity and contingent processing in decision making:

An information search and protocol analysis. *Organizational Behavior and Human Performance, 16,* 366–387.

———. (1982). Contingent decision behavior. *Psychological Bulletin, 92,* 382–401.

Payne, J. W., J. R. Bettman, and E. J. Johnsson. (1988). Adaptive strategy selection in decision making. *Journal of Experimental Psychology: Learning, Memory and Cognition, 14,* 534–552.

Rasmussen, J., K. Duncan, and J. Leplat. (eds.) (1987). *New Technology and Human Error.* Chichester: Wiley.

Rohrmann, B., L. R. Beach, C. Vlek, and S. R. Watson. (eds.) (1988). *Advances in decision research.* Special volume, *Acta Psychologica, 88.*

Samuelson, W., and R. Zeckhauser. (1988). Status quo bias in decision making. *Journal of Risk and Uncertainty, 1,* 7–59.

Schoemaker, P.J.H. (1988). *The scenario approach to strategic thinking: Methodological cognitive and organizational perspectives.* Chicago: Center for Decision Research, University of Chicago.

Simon, H. A. (1955). A behavioral model of rational choice. *Quarterly Journal of Economics, 68,* 99–118.

Soelberg, P. (1967). A study of decision making: Job choice. Ph.D. dissertation, Carnegie Institute of Technology and Massachusetts Institute of Technology.

Staw, B. M. (1976). Knee-deep in the big muddy: A study of escalating commitment to a chosen course of action. *Organizational Behavior and Human Performance, 16,* 27–44.

Staw, B. M., and F. V. Fox. (1977). Escalation: The determinants of commitment to a chosen course of action. *Human Relations, 30,* 431–450.

Sundstroem, G. A. (1989). Information search and decision making: The effects of information displays. In H. Montgomery and O. Svenson (eds.), *Process and structure in human decision making.* Chichester: Wiley.

Svenson, O. (1979). Process descriptions of decision making. *Organizational Behavior and Human Performance, 23,* 86–112.

Svenson, O. (1985). Cognitive strategies in a complex judgment task: Analysis of verbal reports and judgments of cumulated risk over different exposure time. *Organizational Behavior and Human Decision Processes, 36,* 1–15.

Svenson, O. (1992). Differentiation and consolidation theory of human decision making: A frame of reference for the study of human decision processes. *Acta Psychologica, 80,* 143–168.

Svenson, O., and N. Malmsten. (1991). Post-decision consolidation processes in human decision making. *Journal of Scientific Contributions to General Psychology/Communicazioni Scientifiche di Psicologia Generale, 6,* 109–119.

Svenson, O., and L. J. Benthorn. (1992). Consolidation processes in decision making: Post-decision changes in attractiveness of alternatives. *Journal of Economic Psychology, 13,* 315-327.

Tietz, R. (ed.) (1983). *Aspiration levels in bargaining and economic decision making.* Berlin: Springer Verlag.

Tversky, A., and D. Kahneman. (1981). The framing of decision and the psychology of choice. *Science, 211,* 453–458.

Tyszka, T. (1983). Contextual multiattribute decision rules. In L. Sjöberg, T. Tyszka and J. A. Wise (eds.), *Human decision making.* Lund, Sweden: Doxa.

Wallsten, T. S., and C. Barton. (1982). Processing probabilistic multidimensional information for decisions. *Journal of Experimental Psychology: Learning, Memory and Cognition, 8,* 361–384.

von Winterfeldt, D., and W. Edwards. (1986). *Decision analysis and behavioral research.* Cambridge: Cambridge University Press.

Zajonc, R. B. (1980). Feelings and thinking: Preferences need no inferences. *American Psychologist, 35,* 151–175.

# Part Two

# Approaches Based on Management Science/Operations Research

Like any other form of decision-aiding software, management science/operations research (MS/OR) packages involve (1) goals to be achieved, (2) alternatives available for achieving them, and (3) relations between goals and alternatives in order to arrive at (4) tentative conclusions as to which alternative is best. On each of those four elements, MS/OR packages tend to be distinctive from other packages, especially from those oriented toward spreadsheet-based multicriteria decision-making (MCDM) packages.

The typical MS/OR package involves a single goal to be achieved. The single goal may be arrived at by aggregating other subgoals, often by imposing a common measurement unit like dollars so the subgoals can be added together. The alternatives tend to be dichotomies of a go/no-go variety (drawing upon the logic of finite mathematics), or they involve a continuum of alternatives (drawing upon the logic of calculus).

The most common MS/OR packages deal with payoff matrices, decision trees, linear programming, and optimum-level curves in accordance with the most common methods discussed in MS/OR textbooks. A payoff matrix typically involves a dichotomous choice on the two rows, two possible conflicting events or states of nature on the columns, and an indication in the cells of what the payoffs are likely to be to each alternative with the occurrence of each event. This can be contrasted with an MCDM table where the rows consist of a variety of alternatives. There are usually about four in a public policy problem: conservative, liberal, neutral, and mutually optimizing alternatives. An MCDM table also tends to show goals rather than probabilistic events on the columns, and the cells indicate how conducive or adverse the alternatives are to each goal.

Another typical MS/OR format is the decision tree, usually pictured as looking like a tree on its side, with branches and subbranches. The branches generally represent alternative possibilities that depend on the

occurrence or nonoccurrence of probabilistic events. Such a way of depicting a decision-making problem has aesthetic appeal. Unfortunately, that format may have considerable difficulty dealing with multidimensionality, missing information, multiple alternatives, conflicting restraints, and simplicity, especially in seeking to draw a variety of conclusions through trial-and-error experimentation.

A third type of MS/OR software is linear programming. Unlike payoff matrices and decision trees, which emphasize discrete alternatives, linear programming specializes in allocating scarce resources along a continuum of possibilities to a set of variables under various kinds of quantitative constraints. The scarce resources may be money, time, or people. The variables may be activities, places, tasks, or other objects. In terms of form rather than function, linear programming involves maximizing or minimizing an objective function or algebraic expression subject to constraints generally in the form of inequalities like greater than or less than. As with other MS/OR methods, it sounds and looks sophisticated. In reality, it, in effect, fails to recognize that the world is round and that increased allocations of scarce resources to any budget category or goal tends to produce increased benefits but at a diminishing or nonlinear rate. If one attempts to switch to nonlinear versions of linear programming, then one runs the risk of greatly increased complexity and possibly decreased validity as the solution gets stuck on a local peak or in a local hole still looking for the global solution.

A fourth type of MS/OR software involves optimum-level curves. This kind of software is more explicitly oriented toward calculus solutions than other MS/OR software. In theory, it could be especially relevant to finding an optimum level where doing too much or too little is undesirable. The methodology assumes that one can determine an equation showing the relation between varying amounts of a policy input and varying degrees of goal achievement. This is supposed to result in some curves showing a positive nonlinear relation between the policy and various benefits and some curves showing a negative nonlinear relation. By summing the curves, one is supposed to get an overall hill-shaped or valley-shaped curve. The top or bottom indicates the optimum level. Such a system is not so capable of dealing with multiple policies, multiple measurement, or problems in which the relations between the policies and goals tend to be reciprocal or determined by outside factors. Such relations may be especially present in public policy problems, where the social indicators (like crime) have more influence on how much is allocated to various policies (like prisons) than the policies have on the social indicators.

Although MS/OR models may have drawbacks, they also have some advantages over competing MCDM or expert systems models. Decision trees and optimum-level curves, for example, can communicate ideas as visual aids better than a set of expert branching rules or a matrix of alternatives and goals, although that is partly a matter of taste. MS/OR models may work fine with industrial engineering problems where one can obtain the data needed to satisfy the models and where the assump-

tions are realistic, such as linear and nonreciprocal relations. Some MS/OR packages are better than others. One purpose of Part Two is to make comparisons within MS/OR models, as contrasted to the more difficult problem of comparing MS/OR, MCDM, and expert systems models. The MCDM and expert systems models are discussed in Parts Three and Four.

4

# A Comparison of Linear Programming Software on Microcomputers

RAMESH SHARDA

One of the most powerful decision-aiding techniques, which has witnessed tremendous applications and software development, is linear programming (LP). While many other techniques covered in this book are appropriate for decision making, LP is especially important due to its versatility. No other technique has received as much attention as LP in algorithmic development, with the result that very large LP problems can now be solved. As a consequence, LP has been used not only in problems in which linearity is present but also as an intermediary tool where its direct use would not be possible. For example, LP can be used in nonlinear problems where piecewise approximation of the nonlinear functions yields large LP problems. Versions of simplex method have been developed where multiple criteria are present. Thus, LP has been employed as a computing tool where the original problem does not appear to be initially appropriate for linear programming. Thoughtful reformulations can allow LP to be a powerful decision-aid technique. Recent developments in LP software make it ever more attractive.

While LP software for microcomputers has been available ever since the micros became popular, recently there has been a major growth in the power and capability of such software. LP software has now been developed to take advantage of powerful microcomputers (such as 80386-based machines) and certain sophisticated features to enable a decision maker to model, manage, solve, and analyze LP problems more efficiently.

This chapter provides an up-to-date compendium of new packages that solve LPs and reports on the user-interface, user-control, and mathematical programming capabilities of this software. My evaluation also focuses on the performance of each package when solving a set of test problems. Over forty medium to large LPs were solved. On the basis of functional perfor-

mance and other characteristics (such as ease of use), I identify standout systems, make recommendations for product enhancement, and comment on future directions in developing new software.

## LINEAR PROGRAMMING SOFTWARE

Over two dozen LP packages are currently available for MS-DOS computers. Since a recent survey paper (Sharda 1988) has listed the information on availability of these programs, this chapter includes only a list of software introduced or updated since the survey paper was published. (Refer to Sharda 1988 for several other LP programs.) Table 4.1 lists product names, publishers, maximum problem size as stated by the publishers, and prices for commercial customers. Most vendors offer site licenses, significant educational discounts, and smaller versions at lower prices. MINOS and XMP are mainframe programs that have been ported to MS-DOS computers. Their developers note that these programs are still in developmental stage to take advantage of personal computer (PC) architecture and interface.

### User Interface Issues

The major enhancement in LP software has occurred in user interface. Most of the LP software available today is capable of reading LP problems in the Mathematical Programming System (MPS) format. This capability is important for moving LP problems previously solved on a mainframe to a PC. The MPS format also allows for a standard format to exchange problems for different LP systems. Table 4.2 identifies programs capable of reading MPS files. LINDO, XA, MPSX-PC, and XPRESS-LP are also able to save an MPS format file for an LP problem developed using other formats.

Perhaps the most significant recent achievement of LP software vendors has been to develop spreadsheet-compatible programs. Spreadsheet programs have become almost integral parts of microcomputers. Most PC users are familiar with spreadsheets. While this familiarity does not help improve the analytical aspects of formulating an LP problem, the convenient data entry and editing features of spreadsheets make it easy to develop the LP matrix. Spreadsheet programs allow blocks of numbers or relationships to be copied from one location to another. This feature can be useful in developing LP problems that have blocks of similar structure. Report generation and graphics features of spreadsheets can be used for developing final, presentable reports quickly from the optimal solution stored in a spreadsheet file. These features have resulted in the popularity of spreadsheet-compatible LP software. This is the only class of LP software that has received wide coverage in popular media. For example, What's Best! a spreadsheet-based LP package, has been mentioned in the *Wall Street Journal,* and *New York Times.* It also received *PC Magazine*'s Technical Excellence award.

Table 4.2 lists the LP programs compatible with spreadsheets. There are

various degrees of this compatibility. MSLP-PC offers only a spreadsheet-like input/data editor. LPS-867, MPSX-PC, and XPRESS-LP are able to read a problem as well and write the solution to a spreadsheet file. VINO, What's Best! and XA offer the most complete integration with a spreadsheet. These programs can be used from within the spreadsheet program such as Lotus 1-2-3. The user creates an LP model in a spreadsheet file, presses one or two keys to invoke the optimizer, and solves the problem as if some cells were being recalculated. This makes it appear that the spreadsheet program is endowed with an optimizer. If spreadsheet compatibility is a major concern, these programs deserve a careful look. What's Best! can also be purchased with spreadsheet templates for some common LP applications.

As the capability of LP software to solve medium to large problems evolved, it became apparent that such problems would perhaps be developed using matrix generators and modeling languages, similar to the mainframe environment. Most LP problems have only a few types of constraints. Using a modeling language, one needs to enter those equations just once. Similar constraints are automatically generated using only the data defined by the user. Many advances have been made in this area. GAMS, a popular modeling system on the mainframes, has been ported to PC and combined with MINOS to offer a complete modeling and analysis package. GAMS now also includes XMP and Zoom for linear and integer programming problems. FORTLP will be available with a menu-based model development system, CAMPS. Developers of LINDO packages have announced a modeling language, LINGO, for use with their software. An OMNI-like matrix generator will be available for MPSX-PC. XPRESS-LP comes with a fairly complete modeling language.

MPL, a new entry in mathematical programming languages, is not an LP package in itself. Rather, it allows an analyst to build a model using its language and then save the model in several commonly used formats, such as those accepted by XA and LINDO. It can also save the problem in MPS format so that the problem is acceptable to virtually any LP package. This allows one to use MPL as a front end to one's own favorite LP software.

Some packages that do not offer a modeling language have an expressions format available to enter the complete LP problem just as one would write it out. LINDO packages, MILP, MPSX-PC, and XA offer this capability. The options available in the expressions format vary among packages, with MPSX-PC and XA being the most general. This format is quite appropriate for small LP problems. As the problem size increases, one realistically has to use a file generated in MPS format through an external program, a spreadsheet file, or a modeling language.

### Performance Issues

First, we note several programs offering mixed integer programming capability. Two additions to the list of programs with MIP option are XMP and

**Table 4.1**
**General Information on LP Software**

| Software | Publisher | Price | Size of Problem | Remarks |
|---|---|---|---|---|
| FORTLP | Dr. G. Mitra<br>Department of Mathematics<br>and Statistics, Brunel University<br>Uxbridge, Middlesex<br>Great Britain UB8 3PH | * | m≤2,000<br>n≤3,000<br>NZ≤20,000 | Requires a FORTRAN compiler. |
| GAMS/MINOS | GAMS Dev. Corporation<br>2828 Albernarle STNW<br>Washington, D.C. 20008<br>(202) 232-5662 | $1,600 | Depends upon the system configur-ation | Also marketed by The Scientific Press<br>651 Gateway Blvd.<br>S. San Francisco, CA<br>94080-7014,<br>(415) 583-8840. |
| HYPER LINDO | LINDO Systems, Inc.<br>1415 N. Dayton St.<br>Chicago, IL 60622<br>(312) 871-2524 | $1,500 | m≤1,999<br>n≤3,999<br>NZ≤32,000<br>I≤200 | Smaller versions available for lower prices. Marketed by the Scientific Press. |
| LINDO/386 | " " | $2,500 | m≤ 5,000<br>n≤15,000<br>NZ≤100,000 | |
| LPS-867 | Applied Automated Engineering Corp.<br>65 S. Main St., Bldg. B<br>Pennington, NJ 08534<br>(609) 737-6800 | $500 | m≤2,500<br>n≤5,000-m<br>NZ≤16,000 | Smaller versions available for lower prices. |
| MILP | Akademiai Kiado<br>Hungarian Academy of Sci.<br>Varoshaz U. l., H1052<br>Budapest, Hungary | $2,500 | m≤800<br>n≤2,000<br>NZ≤32,000 | |
| MINOS-LP | Systems Optimization Laboratory<br>Department of Operations Research<br>Stanford University<br>Stanford, CA 94305 | * | | |
| MPL | Maximal Software<br>Klapparas II<br>IS-110 Reykjavik<br>Iceland (354-1) 78243 | * | | A Mathematical Modeling Language Compatible with many LP systems. |
| MSLP-PC | CompuED<br>PO Box 35544, Stn. E.<br>Vancouver, B.C.,<br>Canada, V6M 4G8<br>(604) 224-6228 | $80 | m≤200<br>n≤400 | smaller version available for $20. |

**Table 4.1 (continued)**

| Software | Publisher | Price | Size of Problem | Remarks |
|---|---|---|---|---|
| PC-Prog | QMS<br>P.O. Box 12597<br>1110 AN Amsterdam Z-O<br>The Netherlands<br>31-20-865640 | * | $m \leq 250$<br>$n \leq 500$ | Includes quadratic and integer programming. |
| VINO | See LINDO | $695 | $m \leq 2{,}000$<br>$n \leq 4{,}000$<br>$NZ \leq 32{,}000$<br>$I \leq 200$ | Smaller version available at a lower price. Also sold by Scientific Press. |
| What's Best | General Optimization, Inc.<br>2251 N. Geneva Terrace<br>Chicago, IL 60614<br>(800) 441-BEST | $995 | $m \leq 1{,}600$<br>$n \leq 4{,}000$<br>$NZ \leq 32{,}000$<br>$I \leq 400$ | Smaller versions are available at lower prices. Also sold by Holden-Day Inc. 4432 Telegraph Ave., Oakland, CA 94609, (415) 428-9400. |
| XA | Sunset Software Technology<br>1613 Chelsea Road,<br>Suite 153<br>San Marino, CA 91108<br>(818) 284-4763 | $1,195 | $m \leq 6{,}000$<br>$n \leq 26{,}000\text{-}m$<br>$NZ \leq 32{,}000$ | This version requires 80386. Other versions for 8088/80286 machines are available with somewhat reduced size capabilities. |
| XMP | XMP Software, Inc.<br>930 Tahoe Blvd., #802-279<br>Incline Village, NV 89451<br>(702) 831-4967 | | | |
| XPRESS-LP | Dash Associates<br>Blisworth House, Church Lane<br>Blisworth<br>Northants NN7 3BX<br>Great Britain<br>(604) 858993 | £1,500<br><br><br>£875 | $m \leq 1{,}000$<br>$n \leq 2{,}000$ | Smaller version available for a lower price. |

*Note:* m = number of rows, n = number of columns, NZ = number of non-zero elements, E, L, G = number of constraints of each type, I = number of integer variables, * = Available for a small (undetermined) fee.

**Table 4.2**
**Functional Features of LP Software**

| | Integer Prog. | MPS files | Spread Sheet Compatibility | Modeling Language | Detailed Expressions Form[1] |
|---|---|---|---|---|---|
| FORTLP | | X | | X | |
| GAMS/MINOS | X | | | X | |
| Hyper LINDO | X | X | | X* | X |
| LINDO/386 | X | X | | X* | X |
| LPS-867 | | X | X | | |
| MILP | | X | | | X |
| MPSX-PC | X | X | X | X* | X |
| MPL | | | | X | |
| PC-Prog | X | | | X | |
| VINO | X | | X | | |
| What's Best | X | | X | | |
| XA | X | X | X | | X |
| XPRESS-LP | X | X | X | X | |
| MSLP-PC | | | X | | |
| MINOS | ? | X | | | |
| XMP | X | X | | | |

* Available at an additional charge.

[1] Of course, the modeling language option can be used to develop a problem in detailed expressions form.

XPRESS-LP. Sharda (1988) summarizes the numerical limits on integer variables for various programs.

I tested the performance of LP software available to me by solving a number of test problems. Since the test problems were available in MPS format, I tested only those packages that could read MPS files. FORTLP and LINDO/386 were not available in time for the tests reported in this chapter. Further, the publishers of MINOS and XMP stated that the PC versions of their codes were running but not optimized for use on a PC yet and requested that these not be included in the evaluation.

The test set consisted of forty-nine problems collected from a number of sources. Most of these problems are described in Gay (1985). FARM, HEDGE, REFINE, and WILLETT are described in Sharda and Somarajan (1986). These problems range in size from 56 nonzero coefficients to 14,706 nonzeroes. Most of these problems have been accepted as fairly standard as a test set, even for testing mainframe LP codes.

The problems were solved using an IBM PS/2 model '80 computer using Intel 80386/16 MHZ processor and 80387 math coprocessor. This machine has a 44 megabyte hard disk, and 2MB RAM, running DOS 3.3. RAM disk was used wherever possible.

Table 4.3 gives the times for each package to solve problems to within 1 percent of the solution identified by MPSX/370. Errors are marked where a package could not solve a problem. There are a number of possible errors. First, some problems may be too large for a package. This may be clear from the product literature. Occasionally, the initial problem size is acceptable, but the files may become too large for a package as the interactions progress. A second category of errors is due to a package's limitation on accepting MPS files. Our test problems employ fairly general versions of MPS format accepted by MPSX/370, but PC packages occasionally are unable to read them. For example, a program may not accept coefficients in scientific notation, it may not accept RANGES, it may not accept BOUNDS, or it may not accept identical row and column names. These errors can usually be fixed by the user. A third category of errors, rather serious, is in accuracy. A package may solve a problem to an incorrect optimal solution, or it may declare it unbounded or infeasible. Finally, some problems were perhaps so large that the programs got stuck or did not lead to an optimal solution in over nineteen hours, the time limit that a user will find acceptable.

Table 4.3 gives the times for a package to solve each problem and also the various errors. It indicates that no PC package was able to solve all of the forty-nine problems. XA solved the maximum number of problems (forty-six), with accuracy or timing errors on the other three problems. LPS-867 solved forty-two of the problems. XPRESS-LP solved forty-one problems with no accuracy error and six unacceptable format errors. When the format errors were fixed, it was able to solve these six problems as well. This means

Table 4.3
**Test Statistics on a 80386 Machine (in seconds)**

| PROB. NAME | NO. OF ROWS | NO. OF COLS | # NON ZEROS | LINDO | MILP | XA | XPRESS LP | LPS 867 | OAKLAND LP |
|---|---|---|---|---|---|---|---|---|---|
| 25FV47 | 822 | 2393 | 11949 | D | C | 41179 | 7404.95 | A | |
| ADLITTLE | 57 | 154 | 522 | 12.68 | 9 | 9 | 5.71 | 10 | 16 |
| AFIRO | 28 | 60 | 116 | 0.56 | 0.27 | 1 | 2.03 | 1 | 1 |
| BANDM | 306 | 778 | 2963 | 1644.4 | 352 | 210 | 161.09 | 433 | D |
| BAEESEIN | 48 | 108 | 257 | 1.81 | 0.61 | 1 | 1.48 | 1 | C |
| BEACONFD | 174 | 436 | 3650 | 39.87 | 10 | 9 | 13.18 | 112 | 82 |
| BEALE | 171 | 474 | 1073 | 32.19 | 16.48 | 21 | 16.04 | 23 | 92 |
| BERGER | 65 | 198 | 480 | 2.85 | 1.59 | 4 | 14.45 | 4 | 8 |
| BORESD | 234 | 549 | 1759 | 750.73 | 29 | 76 | B | 64 | 112 |
| BRANDY | 221 | 470 | 2371 | 2061.79 | 115.62 | 158 | 56.3 | 169 | C |
| CAPRI | 272 | 625 | 2058 | 158.14 | 108 | 101 | 123.64 | 1058 | D |
| DINAMICO | 417 | 944 | 4394 | D | 2857.9 | 436 | 172.08 | 1076 | D |
| E226 | 226 | 508 | 3264 | 82 | 33.44 | 58 | 24.22 | B | 232 |
| ETAMACRO | 401 | 1089 | 2890 | 421 | 181.04 | 280 | 129.84 | 369 | C |
| FARM | 8 | 20 | 56 | 0.34 | 0.05 | 0 | 1.76 | 0 | 0 |
| FFFFF800 | 525 | 1379 | 6760 | 609.89 | C | 235 | 301.87 | 5592 | |
| FIXMAR | 325 | 777 | 2926 | 438.52 | 94.04 | 133 | 71.84 | 1122 | A |
| FORESTRY | 402 | 1005 | 4196 | 1383 | 470 | 510 | 327.3 | 3342 | A |
| FORPLAN | 162 | 583 | 5078 | 3525 | 121 | 49 | 54.98 | 434 | |
| GFRD-PNC | 617 | 1092 | 3467 | 213.01 | 204 | 352 | 158.4 | 462 | |
| GROW15 | 301 | 646 | 5966 | 3513 | C | 603 | 486.97 | D | A |
| GROW22 | 441 | 1387 | 8759 | A | C | 1184 | C | A | |
| GROW7 | 141 | 442 | 2774 | 438.24 | 568 | 90 | 65.58 | 597 | C |
| HEDGE | 93 | 250 | 480 | 5.39 | 6 | 4 | 6.1 | 53 | 16 |
| ISRAEL | 175 | 317 | 2533 | 111.05 | 57 | 76 | 77.17 | 92 | 173 |
| NESM | 663 | 3586 | 14651 | 9506 | A | 6203 | B | A | |
| PILOT4 | 411 | 1411 | 5556 | A | C | C | 2456.16 | C | |
| PILOT.JA | 941 | 1988 | 14706 | A | A | D | B | A | |
| PROB12B | 381 | 692 | 3373 | 299.19 | 202 | 192 | 86.95 | 1413 | 1324 |
| PROB31B | 384 | 961 | 4668 | 208.57 | 120 | 219 | 102.27 | 1203 | 631 |
| PROB43B | 648 | 1253 | 5368 | 253.86 | 182 | 296 | 128.41 | 1917 | |
| RECIPE | 92 | 272 | 844 | 2.08 | 1.26 | 3 | 4.06 | 4 | 13 |
| REFINE | 30 | 63 | 185 | 0.23 | 1 | 1 | 2.26 | 1 | 1 |
| SC205 | 206 | 409 | 758 | 60.52 | 50 | 45 | 23.23 | 68 | A |
| SCAGR7 | 130 | 270 | 683 | 30.1 | 11 | 9 | 12.41 | 173 | C |
| SCORPION | 389 | 747 | 2097 | C | 71 | 57 | 46.02 | 123 | 484 |
| SCRS8 | 491 | 1660 | 4520 | 581.22 | 507 | 511 | 235.41 | 5136 | D |
| SCSD1 | 78 | 838 | 3226 | 73 | 79 | 47 | 23.95 | 32 | 188 |
| SCSD6 | 148 | 1498 | 5814 | 241 | 171 | 187 | 91.94 | 962 | A |
| SCTAP1 | 311 | 791 | 3683 | 76.02 | 67 | 113 | 59.43 | 725 | A |
| SCTAP2 | 1101 | 2931 | 14395 | 527.56 | A | C | 635.38 | 1497 | |
| SHARE1B | 118 | 343 | 1300 | 125 | 67 | 54 | 31.53 | 57 | 266 |
| SHELL | 537 | 2312 | 5437 | 211.36 | 144 | 266 | 151.21 | 2060 | D |
| SHIP04S | 403 | 1861 | 6213 | 85.29 | 101 | 274 | 104.63 | 148 | |
| STAIR | 357 | 824 | 4214 | C | C | 386 | B | 1488 | |
| STANDATA | 360 | 1435 | 3398 | 10.6 | 12 | 97 | B | 26 | |
| STANDMPS | 468 | 1543 | 4154 | 102.22 | 42 | 142 | B | 75 | D |
| VTP.BASE | 199 | 402 | 1113 | 68.22 | 54 | 42 | B | 118 | |
| WILLETT | 185 | 679 | 2532 | 1327.94 | C | 261 | 131.11 | 2116 | A |
| # PROBLEMS SOLVED CORRECTLY | | | | 42 | 39 | 46 | 41 | 42 | |

*Note:* A = limitation of problem size, B = limitation of input, C = limitation of accuracy, D = package gets stuck (takes too long).

that XPRESS-LP would be able to solve forty-eight of the forty-nine problems. However, Table 4.3 indicates an input format error for XPRESS-LP for these six problems since the other packages were able to accept those problems.

LPS-867, LINDO, and MILP were also able to solve most of the problems, although they had more accuracy of precision errors.

To compare these programs on the basis of speed, I used the pairwise comparison approach suggested by Lootsma (1980). The pairwise rank of package $k$ with respect to package $l$, $\tau_{kl}$ is computed as

$$\tau_{kl} = \frac{(\Sigma T_{ik}/M_{kl})/C(k,l)}{(\Sigma T_{il}/M_{kl})/C(k,l)}$$

where

$T_{ik}$ = $(\text{Min}_k t_{ik})/\ t_{ik}$ is a minimum time ratio,

$t_{ik}$ = running time of package $k$ on problem $i$,

$C(k,l)$ = cross-section of successfully solved problems by packages $k$ and $l$, and

$M_{kl}$ = number of problems successfully solved by both packages.

Table 4.4 shows the pairwise comparison of speed of these LP programs. It shows that XPRESS-LP has a higher rank in speed compared to any of the other packages, based on these test problems. MILP ranks higher than LINDO, LPS-867, and XA. XA ranks higher than LINDO and LPS-867.

These results show that there are some differences in performance of a package in terms of speed. However, all of the times are in an acceptable

**Table 4.4**
**Pairwise Comparison Matrix of Selected LP Packages**

| | LINDO | MILP | XA | XPRESS LP | LPS 867 |
|---|---|---|---|---|---|
| LINDO | | 0.64 (34) | 0.73 (37) | 0.55 (34) | 1.47 (36) |
| MILP | 1.56 (34) | | 1.16 (39) | 0.80 (35) | 2.15 (38) |
| XA | 1.37 (37) | 0.86 (39) | | 0.73 (39) | 2.01 (41) |
| XPRESS-LP | 1.82 (34) | 1.25 (35) | 1.37 (38) | | 2.81 (37) |
| LPS-867 | 0.68 (36) | 0.46 (38) | 0.50 (41) | 0.36 (37) | |

*Note:* The numbers in parentheses indicate the size of the common cross-section between pairs of codes.

range for use on a PC, and thus other features of a program should be carefully weighed in selecting an LP optimizer. VINO and What's Best! use LINDO as the internal optimization tool; their speed performance can be expected to be similar to LINDO's. These comparisons are based on the software versions available as of October 1988. New versions are constantly being developed by LP software vendors.

## FUTURE DIRECTIONS

### Added Hardware Support

Some vendors have attempted to reduce the time to solve large problems by supporting third-party hardware designed for improving arithmetic operations. For example, LINDO/386 can be run using a Weitek floating point coprocessor. A sample problem with 516 rows and 1,035 columns was solved on a Compaq 386/25 MHZ machine using LINDO/386 and Weitek coprocessor in 9 seconds. The same problem took seven minutes, fifty seconds on a PC/XT with 8087 math coprocessor. LPS-867 has been adapted to solve problems using Definicon Systems boards, with a twenty-fold improvement in speed on 80286 computer as compared to a PC/XT. The 80386 version of XA is supposedly able to solve problems 50 to 500 percent faster than earlier versions. XPRESS-LP is being modified to work with parallel processors on microcomputers. Thus, it is clear that LP software developers are moving to take advantage of hardware enhancements. More work in this area will likely lead to mainframe performance on micros in a short time.

### User Interfaces

More developments are expected in modeling languages. Efforts are underway to generate an LP problem automatically using expert systems and natural language processing technology. Intelligent interpretations of solutions produced by optimizers are also being developed (Greenberg 1987). We can also expect windows-based problem development interfaces as the new operating environments become more popular. A related growth field will be graphics-based model development systems.

### Domain-Specific Models

Microcomputers offer the potential for extending the benefits of operations research modeling to a much larger audience than was possible with mainframes. This will be facilitated by providing templates of LP models formulated for specific problems. What's Best! is available with templates for several common LP applications. Using hypertext technology, this can be done for many other applications.

It is clear that the LP software is constantly improving to exploit the advances in microcomputers. We are already able to solve problems with several thousand nonzeroes on a PC. The forthcoming advances in user interfaces and model development systems are likely to make LP systems even more accessible for decision making.

## REFERENCES

Arden, B. W. (1980). *What Can Be Automated? The Computer Science and Engineering Research Study,* MIT Press, Cambridge, Massachusetts.

Bisschop, J., and A. Meeraus. (1982). "On the development of a general algebraic modelling system in strategic planning environment." *Mathematical Programming Study, 20,* 1-20.

Gay, D. M. (1985). "Electronic mail distribution of linear programming test problems." *COAL Newsletter, 13* (December), 10-12.

Greenberg, H. (1987). "ANALYZE: A Computer Assisted Analysis System for Linear Programming Models." *Operations Research Letters, 6*(5), 249-255.

Ho, J. K., and I. Loute. (1981). "A set of staircase linear programming pest problems." *Mathematical Programming, 20,* 245-250.

Lootsma, F. A. (1982). "Performance evaluation of nonlinear optimization methods via multi-criteria decision analysis and via linear model analysis." In *Nonlinear Optimization 1981,* pp. 419-453. Edited by M.J.D. Poweke. Academic Press, New York.

Murtagh, B. A., and M. A. Saunders. (1982). "A projected Lagrangean algorithm and its implementation for sparse nonlinear constraints." *Mathematical Programming Study, 16,* 84-117.

Sharda, R. (1988). "The state of the art of linear programming on personal computers." *Interfaces, 18*(4), 49-58.

Sharda, R., and Guha, A. (1988). "Microcomputer LP Systems: A Performance Comparison." Working paper, Oklahoma State University.

Sharda, R., and C. Somarajan. (1986). "Comparative performance of advanced microcomputer LP systems." *Computers and Operations Research, 13*(2/3), 131-147.

5

# Influence Diagrams for Decision Analysis

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## DECISION ANALYSIS-BASED DECISION SUPPORT

Decision analysis (Keeney 1982; Raiffa 1970; Samson 1988; von Winterfeldt & Edwards 1986), the application of decision theory to real-world problems, has been referred to as the oldest, best established, and most articulate school of decision support systems modeling (Stabell 1987). Decision analysis focuses not on modeling a system but on modeling the decision (von Winterfeldt 1988). It provides methods for decomposing problems into sequences of choices, outcomes, events and their associated probabilities, and estimates of the preferences of decision makers for outcomes. The founding principle is that humans can process fragmented knowledge in the other forms reliably but have difficulty dealing with the aggregation of the fragments as complex problems (Leal & Pearl 1977).

Decision analysis has been successfully and extensively applied to less well-structured problems (see Corner & Kirkwood 1991 for a recent survey of decision analysis applications). Keeney (1982) and Ulvila and Brown (1982) list a number of cases, as well as a number of large organizations that, by establishing groups within the organization, have committed themselves to the ongoing application of decision analysis. The many published cases include public utility technology choice (Keeney, Lathrop & Sicherman 1986), nuclear power plant site selection (Kirkwood 1982), information technology strategy (Brooks & Kirkwood 1988; Williams 1986), new product development (Conway 1986), manufacturing strategy (Samson 1987), and general insurance strategy (Samson 1986). These cases and others provide evidence of the wide applicability of decision analysis to decision support.

A major barrier to the further expansion of the use of decision analysis is the level of expertise needed to carry it out; many decision makers require

intermediaries between them and the computing and modeling techniques to solve their problems. An important part of the expertise of the decision analyst is the art of structuring problems. This chapter proposes a method for structuring problems based on influence diagrams that will enable more decision makers to avail themselves of the power of decision analysis.

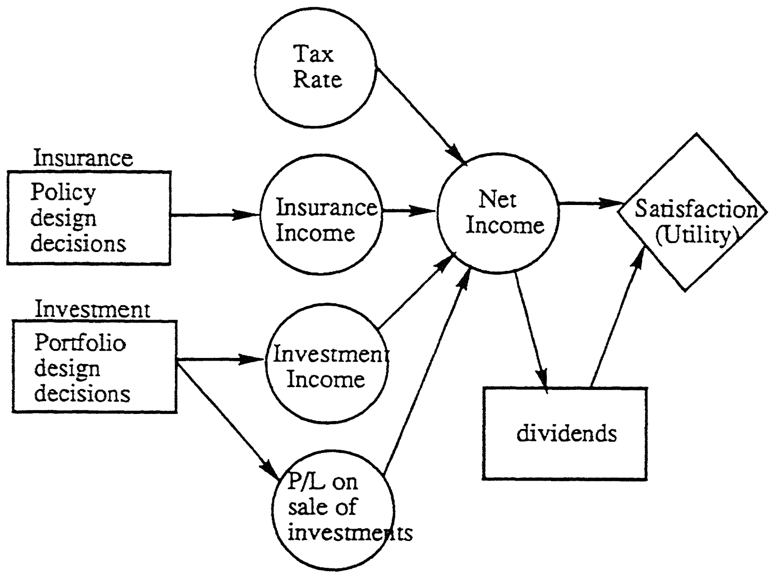
## REPRESENTING DECISION PROBLEMS AS INFLUENCE DIAGRAMS

Decision analysis problems can be represented by decision trees; however, influence diagrams (Agogino & Rege 1987; Barlow 1988; Shachter 1988; 1986), a more recent representation, facilitate the development of decision models. Influence diagrams are Bayesian belief networks (Pearl 1988), which include decision and outcome nodes. They have already been applied in problems relating to construction risk management (Ashley, Stokes & Perng 1988), environmental management (Varis & Kettunen 1988), milling plant management (Agogino, Guha & Russell 1988), petroleum geology (Reid et al. 1985), forensic science (Lou & Gammerman 1990), health technology assessment (Shachter, Eddy & Hasselblad 1988), and therapy planning (Quaglini et al. 1989).

Influence diagrams are a network of choice, event, and outcome nodes (Figure 5.1). Choice nodes are represented as rectangles, event nodes as circles, and outcome nodes as diamonds. The choice nodes describe decisions. Inside decision nodes are the alternatives that may be selected by a decision maker. Event nodes can represent endogenous and exogenous events and states that are probabilistic or deterministic. Probabilistic or chance events are described internally by probability distributions. Deterministic events represent variables that can be determined precisely once their predecessors are known. Outcome nodes represent goal states and contain a function used to measure selected policies. Links into events show other events and decisions that condition that event. Links into decision nodes show information that is known when that decision is made.

An influence diagram can be viewed from three levels: the relational level, the numerical level, and the functional level (Moore & Agogino 1987). The labeled nodes and arcs describe a problem at the relational level, showing the major problem components and their interdependence. Once built at the relational level, the influence diagram can be specified at the numerical level. This can be seen as specifying the internal values of nodes, the alternatives in choice nodes, the probability distributions in probabilistic events, and the functions in deterministic events and the outcome node. A numerically specified influence diagram can be solved to produce a solution in the form of the set of decisions that maximize expected utility.

**Figure 5.1**
**Insurance Planning Model**




## SOLVING INFLUENCE DIAGRAMS

Horvitz, Breese, and Henrion (1988) have described a number of approaches to solving influence diagrams and propagating belief through Bayesian belief networks: brute force methods, exact methods, and stochastic simulation. Brute force methods calculate the joint distribution for a particular variable, from which marginal probabilities for any value can be obtained by summing over the relevant values in the joint distribution. The difficulty with this approach is that the computational task increases exponentially as the number of variables increases, and the method is impractical for more than a few variables.

Exact methods exploit the topology of networks. They are restricted to particular topologies, analyze a particular diagram before selecting a least-cost solution strategy, or manipulate the topology of a diagram before solving it. The best-known exact method for solving influence diagrams is the algorithm developed by Shachter (1986). Although exact approaches are less expensive in terms of solution time than brute force approaches, they have also been shown to be susceptible to NP hardness (Cooper, 1987).

Stochastic simulation methods are typified by the iterative two-phase simulation method that has been successfully applied in risk construction (Ashley, Stokes & Perng 1988). In the first phase, a variable distribution is

computed from its neighbors. The second phase samples a new value from the distribution computed in phase 1 and then reevaluates the distribution in the diagram. An advantage of this approach is that this procedure may be able to be implemented by carrying out some operations in parallel (Horvitz, Breese & Henrion 1988).

Solution methods for influence diagrams are a matter of ongoing research. The traditional decision analysis approach to overcome computational difficulties is to keep problems small and tractable using attention-focusing heuristics (Holtzman 1989). These heuristics keep factors that have the greatest impact on the solution in the problem while removing those that are insignificant. Algorithms such as Shachter's (1986) combined with these heuristics provide a practical solution means for reasonably large problems expressed as influence diagrams.

## USING INFLUENCE DIAGRAMS TO STRUCTURE PROBLEMS

Influence diagrams are superior to decision trees in their expressive power and their flexibility in structuring problems. An influence diagram can show the major concepts in a problem, separated from the values that variables representing these concepts may take. This allows influence diagrams to represent large problems more concisely, enabling better communication for problem structuring and verification. Influence diagrams are used here as a grammar for communicating problem structure.

Influence diagrams provide a medium with which the expert decision analyst may be comfortable, as well as a means of communication between the analyst and the decision maker. They provide a mediating knowledge representation, a desirable feature of knowledge acquisition tools (Bradshaw et al. 1991). The following conversion process is supported:

verbal description → influence diagram → solution.

The ability to present models as high-level diagrams is a common and successful means of overcoming human cognitive limitations (Pearl & Verma 1987). Graphic displays have been advocated as a means of external memory that is readily understood and accessed by users, and there is evidence that some users develop better understanding of a decision environment using such aids (Pracht & Courtney 1988). It is envisaged that the decision maker, with appropriate training and software support, will be able to develop decision models working directly with influence diagrams.

Howard (1989) has described a relevance diagram (an influence diagram without choice nodes) as a means to "get fragmented information out of people's heads, onto paper, and ultimately into a computer." The fragmentation into events allows appropriate experts to address only those parts of the problem where their expertise is applicable. Howard illustrates this in a rele-

vance diagram to estimate the price of oil in the year 2010. The marginal and conditional probabilities of relevant factors, such as scientific developments, political change, and exploration technology, are best assessed by appropriate and different experts.

Decision trees have been grown from the root out by specifying a sequence of decision alternatives and events (Leal & Pearl 1977). Pearl, Leal, and Saleh (1982) have criticized this approach as not being compatible with the way decision makers structure problems. Further, the variables in a decision tree may be sequenced in more than one way. The tree used to assess probabilities is not the same as the one needed for decision making, and the assessment tree must be "flipped" to produce the decision tree (see, for example, Call & Miller 1990). Influence diagrams support different approaches to problem structuring while maintaining a model that represents the decision makers' view of the problem that can be solved.

Influence diagrams support the development of models in the more compatible method of "forward-driven" action/event scenarios suggested by Pearl (1982). For complex problems, not all actions are known, and a "goal-driven" unraveling of a tightly woven cause-effect network is helpful. Keeney (1982) has also supported this approach to elicit more alternative choices when there are too few. Influence diagrams support a goal-driven approach in which the decision maker isolates relevant decisions and events and decomposes the problem by posing the question, "What variable can reduce the uncertainty about this variable?" (Owen 1984).

The direction in which knowledge is elicited using influence diagrams can also change. For example, Shachter and Heckerman (1987) have suggested that sometimes the cause-effect direction may be a more appropriate means of capturing expert knowledge than state-cause.

The first step in a decision analysis is the elicitation of problem elements and their relationships. Text analysis with decision trees as the target structure has been used by Gallhofer and Sarris (1988). The coders are given a description of decision trees and instructions for their coding. The process requires the "bottom-up" coding of subtrees from fragments of text, the combination of subtrees, and then the development of an overview tree. It is strongly advocated here that the ability to separate the relational model from the numerical and functional levels will facilitate text analysis.

The approach taken here, and supported by other researchers (Ashley, Stokes & Perng 1988; Bradshaw & Boose 1990; Bradshaw et al. 1991; Henrion 1989; Ramaprasad & Poon 1985), is to exploit the relational ability of influence diagrams and to build a qualitative model first. This can be expanded quantitatively later. The development of a qualitative structure is a labor- and knowledge-intensive task. Henrion (1989) reports that it took a day of structured interviewing by an experienced decision analyst to elicit a problem structure of thirty variables from a knowledgeable domain expert. One aim of problem structuring is to reduce the skill and time necessary to

produce a qualitative model while still giving the decision maker the understanding of the problem necessary to implement the policy with confidence.

## TEXT ANALYSIS TO PRODUCE INFLUENCE DIAGRAMS

The approach proposed here is similar to that proposed by Ramaprasad and Poon (1985) for building the influence diagrams used in systems dynamics. These systems dynamics influence diagrams differ primarily from the Bayesian influence diagrams in that they include feedback; that is, they are cyclic graphs. There are, however, some useful similarities in their construction. They proposed a technique with the steps of specifying the framework, specifying elements, specifying relationships between elements, specifying the strength of relationships between elements, and mapping the systems dynamics influence diagram.

The specification of the framework provides the categories of variables (they call them elements). This step is unnecessary when building Bayesian influence diagrams as the predetermined categories of decision, chance, and deterministic events and outcomes must be used. One other difference is the use of a matrix to show the links between elements. Ramaprasad and Poon (1985) claimed that this would appeal to more users. They were unable to provide a convincing argument to support this, and until there is reliable empirical evidence to the contrary, the graphic form of influence diagrams will be advocated. The others steps of their technique are used as they are.

Text analysis with influence diagrams as a target structure is driven by the user and allows for the analysis of problems expressed in fragments of text such as a number of paragraphs. Such fragments of text are an appropriate communication medium for managerial users. Text is analyzed and variables or more abstract descriptions of actions, events, and goals elicited. The key step in this activity is the ability to consider relationships in isolation. For each isolated variable, the question is asked, "Does this variable directly influence another variable?" The influences and informational links that are isolated can be used to build influence diagrams.

With less-well-structured problems, the approach to modeling is primarily exploratory. Top-down progressive refinement is made possible by the ability to construct a hierarchy of influence diagrams (Rege & Agogino 1988). Within each fragment of text, the elements and their relationships can be determined in isolation from the rest of the model. The ability to represent problems at different levels of abstraction and the separation of the relational and numerical representation help overcome human cognitive limitations in information processing.

The interactive processing of diagrams at the numerical level will provide feedback necessary to focus attention on those parts of the problem about which there is least confidence or to which policy is most sensitive (Owen 1984). Strategic management problems often require deep knowledge that

can generate a large search space. The ability to deal only with those elements of the problem to which the outcome is sensitive can make the solution of such problems feasible.

The true potential of using text analysis depends on advances in natural language processing. There is difficulty in understanding unrestricted natural language input. Decision analysis provides a fixed number of components upon which text analysis can focus and their integration into an influence diagram. The aim is to build a proper influence diagram or an influence diagram that provides an unambiguous view of the world (Shachter 1986). If user input is reasonably constrained to fit the target structure, the synthesis and checking of an influence diagram is an achievable task.

The combination of top-down text analysis and real-time sensitivity analysis within the decision analysis framework is a promising means of providing the sort of effective support for the process of decision making that could be as easily and widely embraced as spreadsheet software. Even without the automation of text analysis, it may provide the key to a "cookbook"-style methodology that can be used, by analysts or in conjunction with some automation, to construct influence diagrams.

## A TEXT ANALYSIS PROCEDURE

The overall process involves the successive analysis of text, numerical specification, and sensitivity analysis. The following steps can be used to develop a "first-cut" influence diagram.

*Step 1.* Write a description of the problem in simple declarative sentences. This step overcomes the difficulty of reading sentences with complex clausal structures.

*Step 2.* Identify and isolate decision elements. The major concepts can be listed and classified according to whether they are decisions (involve choices), events, or outcomes. Rarely are these elements explicitly, completely, and uniformly referenced in natural language, and this step can require considerable analytical skill. Typical text includes a mixture of concepts, synonyms of concepts, and values. This phase consists of the careful examination of noun phrases in the text.

*Step 3.* Establish relationships between decision elements. The following are possible:

- Interdependence between decisions.
- Effect of one event on another.
- Effect of a decision on a goal (outcome).
- Effect of an event on a decision.
- Effect of an event on a goal (outcome).

Different types of relationships can be used in combining decision elements. Paradice (1988) has described a number of relevant relationships:

- *Causal relationships,* typically established by verb phrases equivalent to "results in," "leads to," and "initiates." There are three conditions for a causal relationship: one event must precede a second event, there must be a relationship that can be formulated between two events, and there must be some justification for believing the relationship is causal. This relationship is the most frequently used. Henrion (1989) points out that the concept of an influence is unclear but that cause-effect is a useful heuristic for establishing influence.
- Derived or definitional relationships, where one event is determined from another action or event. For example, net income can be readily determined from sales and total costs. Such relationships are present for deterministic variables on an influence diagram.
- Bounding relationships, where one event determines the upper or lower limit of another. For example, the lower and upper limits for dividends are bounded by income.
- Information relationships, where an event may have an impact on a decision. For example, the result of a test may be useful in determining whether a more costly action, such as to implement a reliability program, may be taken.

*Step 4.* Draw the influence diagram. Examine each node and determine its type: decision, probabilistic event, or deterministic event.

*Step 5.* Add the goal node. If a goal node does not exist, it may be necessary to add a goal and an arc from all events that influence the goal. A goal may not be explicitly defined, or it may simply be concealed as an event. Another common occurrence is that the decision may have multiple objectives, and there will be a number of goals. When this occurs, it is necessary to create a single outcome node. All other outcome nodes must be converted to events and linked to the single outcome node.

At this point a first-cut influence diagram has been developed. The next phase is to examine each of the nodes, to check for clarity and to expand them if necessary.

## A TEXT ANALYSIS EXAMPLE

Following is an example of a problem description from which the relational model shown in Figure 5.1 could be built:

*Example:* Our main income is from insurance premiums. We aim to derive as much income as possible from selling insurance policies by designing attractive policies. The income from the insurance policies is used to generate further income from investments in shares and property. We also derive some income from the sale of these investments from time to time. We try to maximize retained earnings and to pay a satisfactory dividend to shareholders. Our most critical decisions are the design of

our policies as these affect the overall level of premiums we receive and the claims we must settle, and the design of our investment portfolio.

This is a typical high-level description of a strategic problem. It embodies a description of the business, the goals of the business, and the major decisions. Such a description could be prepared by a high-level manager and comprehended by the decision analyst. To facilitate analysis, it is suggested that guidelines be prepared for the manager and an educational program be undertaken. A short demonstration will have a very positive impact on performance. These guidelines can be part of the entire process of developing an influence diagram from a problem or domain description. Typical analysis can be made as follows.

*Step 1.* Rewrite as simple sentences:

- Main income is derived from insurance premiums.
- Attractive policy design leads to insurance premiums sales.
- Income is derived from investments.
- Income is derived from investments sale.
- Retained earnings produce satisfaction.
- Dividends produce satisfaction.

*Step 2.* Isolate the decision elements:

- Insurance premiums (probabilistic variable).
- Investment income (probabilistic variable).
- Dividends (decision).
- Net income (deterministic variable).
- Policy design (decision).
- Portfolio design (decision).
- Satisfaction (goal).

*Step 3.* Establish relationships. In this case we have added the "tax rate → net income" relationship. This influence, although not indicated in the original problem statement, may emerge from common business knowledge associated with the definition of retained earnings:

- Policy design → insurance premiums investment.
- Portfolio design → investment income.
- Investment sales → net income.
- Investment income → net income.
- Insurance premiums → net income.

- (Tax rate → net income).
- Portfolio design → investment income.
- Portfolio design → investment sales.
- Retained earnings → satisfaction.
- Dividends → satisfaction.

*Steps 4 and 5.* Combine related concepts in an influence diagram and determine the goal node. This results in the diagram shown in Figure 5.1.

## QUANTIFYING THE INFLUENCE DIAGRAM

After the first-cut influence diagram is constructed, the next step is to specify it numerically. Henrion (1989) has provided a procedure for this. The first step is to specify levels for each variable. For example, insurance income might be classified as {depressed, low, average, high, booming}. These can then be converted to numbers such as {1.0M, 1.4M, 1.75M, 2.0M, 2.5M}.

The second step is to quantify the influences between probabilistic events. The domain expert, by including a link in the text analysis procedure, has implied a conditioning influence and a direction of influence. The conditional probabilities for all events that influence a particular event may also initially be specified linguistically. Henrion (1989) has suggested a set of numeric values {0, 0.01, 0.02, 0.05, 0.1, 0.2, 0.3, 0.5, 0.7, 0.8, 0.9, 0.95, 0.98, 0.99, 1.0}, which can be reliably assessed and are sufficient for most problems. Methods such as those proposed by Hamm (1991) can be used to convert the linguistic expressions to numeric expressions of belief.

The quantification procedure may lead to revision of the procedure. For example, the qualitative model may show conditional dependence between an event V and two other events, C1 and C2. On assessment of $P(V \mid C1, C2)$ it may be found that they are independent. One conclusion is that they are independent and the links can be removed and the diagram rechecked. Another explanation may be the presence of "hidden variable," H, not elicited in the qualitative modeling phase. For example, it may be that H is dependent on C1 and C2 and the appropriate assessments are $P(H \mid C1, C2)$ and $P(V \mid H)$.

Once the model has been quantified, it should be validated by sensitivity analysis and testing using scenarios.

## PARTITIONING LARGE INFLUENCE DIAGRAMS

It is aimed to keep influence diagrams small by restricting the number of nodes in a diagram to, say, 7 +/− 2, so that they can be easily solved. This also has the advantage that problem descriptions can be represented at one level. To describe a problem fully, it may be necessary to represent, at least

initially, a large number of nodes. Not all of these nodes need to be considered at once; however, they represent a set of nodes that may be drawn in to the problem structure if necessary. These larger representations may be necessary to assure users that all major problem components have been isolated.

The partitioning of problems into subproblems is a useful mechanism for maintaining completeness while allowing users to access and understand details. Heckerman (1990) has described similarity networks for diagnosis problems. Similarity networks can be used to decompose large subproblems when the influence diagram contains only a single decision (the diagnosis) and a large number of chance nodes.

A more general method is required for constructing influence diagrams for less-well-structured problems. A top-down approach is proposed here. A first-level diagram is developed to isolate major events, decision, and an outcome node. This diagram must be proper, that is, it must be a directed acyclic graph (Shachter 1986) with a single outcome node. It is proposed that partitioning be based on the expansion of influences.

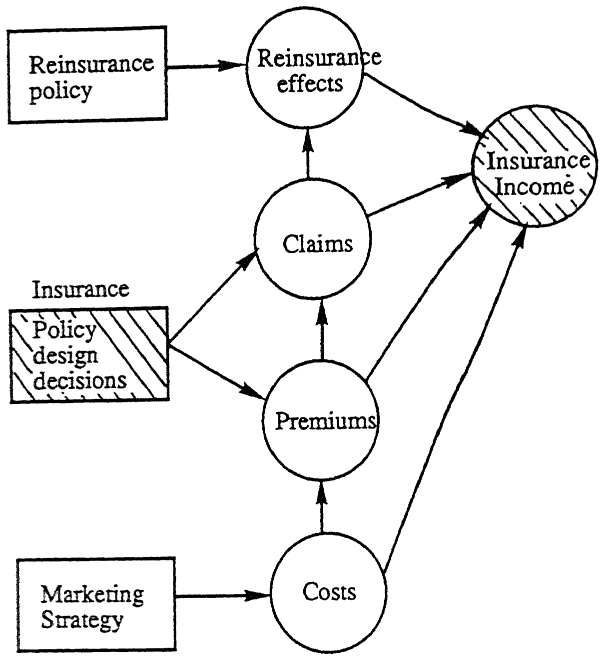
The need to expand a model may result from attempts to assess nodes or as a result of deterministic or probabilistic analysis. Estimated (or historical) values and the variability of individual nodes can be assessed. The model may reveal that insurance premium income is the most important variable contribution to net income but that the effect of policy design on insurance income is too crude. The influence "Policy Design Decisions" → "Insurance Income" could be expanded through text analysis to provide a subdiagram that includes further significant model elements, such as reinsurance effects claims and costs, as shown in Figure 5.2.

The shaded nodes are those that are included in the higher-level diagram. There are two types of shaded nodes: sources, which have only outgoing influences, and sinks, which have only incoming influences. When expanding an influence, the sending node will be a source and the receiving node a sink. Unshaded nodes are new nodes, introduced first at this level. These nodes can be assessed numerically. Subdiagrams differ from overview diagrams and single-level diagrams in the following ways:

1. The subdiagrams need not have an outcome node.
2. Any node that is a sink should be shaded, that is, it should exist in a higher-level diagram (this is not true of source nodes), or it is a barren node and can be safely removed.
3. The integration of subdiagrams and the top-level diagram should result in a proper influence diagram.

The partitioning of problems is principally aimed at providing a communication device for users that allows large problems to be described completely. The diagram must still be solved from a complete reconstruction of

**Figure 5.2**
**Insurance Income Subdiagram**




the constituent subdiagrams to a single-level diagram. A fruitful area of future research may be to exploit the partitioning and to look for conditions under which subdiagrams can be solved locally.

## CONCLUSION

A "cookbook" text analysis procedure provides a means of capturing initial problem knowledge, encouraging the decision maker to think about the problem in a structured way. It may also be a basis for some automation of problem structuring in combination with advances in natural language processing. Combined with the model refinement heuristics (for example, Moore & Agogino 1987), it may be possible to develop software that widely supports the process of decision making.

Such software must be able to handle very different levels of abstraction from the initial sketchy description to a highly detailed and quantified analysis. Strong linguistic abilities would be desirable, to build models from complex fragments of text by referencing factual and semantic knowledge from domain databases, commonsense business knowledge bases, and previous decisions.

Computational linguistics is hard, and unrestricted natural language requires semantic analysis beyond the current capabilities of computer science. Even without automation, text analysis can be the basis of a manual method for the development of decision models much in the way that data models are constructed. Decision makers will gain the benefit of problem understanding, as well as that of improved decisions.

## REFERENCES

Agogino, A. M., R. Guha, and S. Russell. (1988). Sensor Fusion Using Influence Diagrams and Reasoning by Analogy: Application to Milling Machine Monitoring and Control. In *AIENG88 – Third International Conference on Applications of Artificial Intelligence in Engineering.* Computational Mechanics Institute, Southampton, England.

Agogino, Alice M., and Ashutosh Rege. (1987). IDES: Influence Diagram Based Expert System. *Mathematical Modeling, 8,* 277–283.

Ashley, D. B., S. L. Stokes, and Y. H. Perng. (1988). Combining Multiple Expert Assessments for Construction Risk Identification. In *Proceedings of the Seventh International Conference on Offshore Mechanics and Arctic Engineering,* Houston, Texas, February 7–12, American Society of Mechanical Engineers.

Barlow, R. E. (1988). Using Influence Diagrams. In C. A. Clarotti and D. V. Lindley (eds.), *Accelerated Life Testing and Expert's Opinions in Reliability.* Berkeley: University of California Press, pp. 145–157.

Bradshaw, Jeffrey M., and John H. Boose. (1990). Decision Analysis Techniques for Knowledge Acquisition: Combining Information and Preferences Using Aquinas and Axotl. *International Journal of Man-Machine Studies, 32,* 121–186.

Bradshaw, Jeffrey M., Stanley P. Covington, Peter J. Russo, and John H. Boose. (1991). Knowledge Acquisition Techniques for Decision Analysis Using AXOTL and AQUINAS. *Knowledge Acquisition, 3,* 49–77.

Brooks, Daniel G., and Craig W. Kirkwood. (1988). Decision Analysis to Select a Microcomputer Networking Strategy: A Procedure and a Case Study. *Journal of Operational Research Society, 39*(1), 23–32.

Call, Hollis J., and William A. Miller. (1990). A Comparison of Approaches and Implementations for Automating Decision Analysis. *Reliability Engineering and System Safety, 30,* 115–162.

Conway, Walter. (1986). Application of Decision Analysis to New Product Development – A Case Study. In G. Mitra (ed.), *Computer Assisted Decision Making.* Amsterdam: North-Holland.

Cooper, G. F. (1987). Probabilistic Inference Using Belief Networks is NP-hard. Technical Report KSL-87-27. Medical Computer Science Group, Stanford University.

Corner, James L., and Craig W. Kirkwood. (1991). Decision Applications in the Operations Research Literature, 1970–1989. *Operations Research, 39*(2) (March–April), 206–219.

Freiling, Michael J., and James H. Alexander. (1984). Diagrams and Grammars: Tools for Mass Producing Expert Systems. In *Proceedings of First Conference on Artificial Intelligence Application.* Sponsored by IEEE and American Association of Artificial Intelligence, Denver, December 5–7.

Gallhofer, I. N., and W. E. Sarris. (1988). A Coding Procedure for Empirical Research of Political Decision-making. In William E. Sarris and Irmtraud N. Gallhofer (eds.), *Sociometric Research,* vol. 1: *Data Collection and Scaling.* New York: Macmillan.

Hamm, Robert M. (1991). Selection of Verbal Probabilities: A Solution for Some Problems of Verbal Probability Expression. *Organizational Behaviour and Human Decision Processes, 48,* 193–223.

Heckerman, David. (1990). Probabilistic Similarity Networks. *Networks, 20,* 607–636.

Henrion, Max. (1989). Some Practical Issues in Constructing Belief Networks. In *Uncertainty in Artificial Intelligence, 3,* 161–173. Edited by L. N. Kanal, T. S. Levitt, and J. F. Lemmer. Amsterdam: North-Holland.

Hink, Robert F., and David L. Woods. (1987). How Humans Process Uncertain Knowledge: An Introduction for Knowledge Engineers. *AI Magazine* (Fall), 41–53.

Holtzman, Sam. (1989). *Intelligent Decision Systems.* Reading, Mass.: Addison-Wesley.

Horvitz, Eric J., John S. Breese, and Max Henrion. (1988). Decision Theory in Expert Systems and Artificial Intelligence. *International Journal of Approximate Reasoning, 2,* 247–302.

Howard, Ronald A. (1989). Knowledge Maps. *Management Science, 35*(8), 903–922.

Keeney, Ralph L. (1982). Decision Analysis: An Overview. *Operations Research, 30*(5) (September), 803–838.

Keeney, Ralph L., John F. Lathrop, and Alan Sicherman. (1986). An Analysis of Baltimore Gas and Electric Company's Technology Choice. *Operations Research, 34*(1), 18–39.

Kirkwood, Craig W. (1982). A Case History of Nuclear Power Plant Site Selection. *Journal of Operational Research Society, 33*(4), 353–363.

Leal, Antonio, and Judea Pearl. (1977). An Interactive Program for Conversational Elicitation of Decision Structures. *IEEE Transactions on Systems, Man and Cybernetics,* Vol. SMC-7, no. 5, 368–376.

Lou, Z., and A. Gammerman. (1990). A Probabilistic Reasoning System Based on a Causal Graph Approach. *IEE Colloquium on Knowledge Engineering,* no. 17, 4/1–3.

Moore, Eric A., and Alice M. Agogino. (1987). INFORM: An Architecture for Expert-Directed Knowledge Acquisition. *International Journal of Man-Machine Studies, 26,* 213–230.

Owen, D. L. (1984). The Use of Influence Diagrams in Structuring Complex Decision Problems. In D. W. Bunn (ed.), *Applied Decision Analysis.* New York: McGraw-Hill.

Paradice, D. B. (1988). Databases and Knowledge Bases in Managerial Expert Systems. In *Artificial Intelligence: Implications for Computer Integrated*

*Manufacturing,* pp. 403–432. Edited by A. Kusiak. Bedford, U.K.: IFS (Publications) Ltd.

Paradice, D. B., and James F. Courtney. (1986). Dynamic Construction of Models in Managerial Expert Systems. Working paper. College of Business Administration, Texas A&M University, April.

Pearl, Judea. (1988). *Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference.* San Mateo, Calif.: Morgan Kaufman.

Pearl, Judea, Antonio Leal, and Joseph Saleh. (1982). GODDESS: A Goal Directed Decision Structuring System. *IEEE Transactions on Pattern Analysis and Machine Intelligence,* PAMI-4, *3* (May), 250–262.

Pearl, Judea, and Thomas Verma. (1987). The Logic of Representing Dependencies by Directed Graphs. In *Proceedings of the 6th National Conference on AI* (AAAI-87), Seattle, pp. 374–379.

Pracht, William E., and James F. Courtney. (1988). The Effects of an Interactive Graphics-Based DSS to Support Problem Structuring. *Decision Sciences, 19,* 598–621.

Quaglini, Silvana, Carlo Berzuini, Ricccardo Bellazzi, Mario Stefanelli, and Giovanni Barosi. (1989). Therapy Planning by Combining AI and Decision Theoretic Techniques. In *Proceedings of Second European Conference on Artificial Intelligence in Medicine,* pp. 125–134.

Raiffa, Howard. (1970). *Decision Analysis: Introductory Lectures on Choices under Uncertainty.* 2d ed. Reading, MA: Addison-Wesley.

Ramaprasad, Arkalgud, and Eric Poon. (1985). A Computerized Interactive Technique for Mapping Influence Diagrams (MIND). *Strategic Management Journal, 6,* 377–392.

Rege, Ashutosh, and Alice M. Agogino. (1988). Topological Framework for Representing and Solving Probabilistic Inferencing Problems in Expert Systems. *Transactions of IEEE: Systems, Man and Cybernetics, 18,* no. 3.

Reid, C. A., R. M. Fung, R. M. Tong, and E. Tse. (1985). A Knowledge Representation for Reasoning About Petroleum Geology. In *Proceedings of Second Conference on Artificial Intelligence Applications: The Engineering of Knowledge Based Systems,* pp. 125–129. Washington, D.C.: IEEE Computer Society Press.

Samson, Danny. (1986). Expected Utility Strategic Decision Models for General Insurers. *Astin Bulletin, 165,* 545–558.

———. (1987). A Decision Analysis Based DSS for Formulating Manufacturing Strategy. Working paper. Graduate School of Management, University of Melbourne.

———. (1988). *Managerial Decision Analysis.* Chicago: Irwin Books.

Sarris, Willem E., and Irmtraud N. Gallhofer. (1984). Formulation of Real Life Decisions: A Study of Foreign Policy Decisions. *Acta Psychologica, 56,* 247–265.

Shachter, Ross D. (1986). Evaluating Influence Diagrams. *Operations Research, 34*(6) (November–December), 871–882.

———. (1988). Probabilistic Inference and Influence Diagrams. *Operations Research, 36*(4) (July–August), 589–604.

Shachter, Ross D., David M. Eddy, and Victor Hasselblad. (1988). An Influence Diagram Approach to Confidence Profile Method for Health Technologies Assessment. In *Proceedings of Conference on Influence Diagrams for Decision Analysis, Inference and Prediction,* University of California, Berkeley, May 9–11.

Shachter, Ross D., and David E. Heckerman. (1987). Thinking Backward for Knowledge Acquisition. *AI Magazine* (Fall), 55–61.

Stabell, Charles B. (1987). Decision Support Systems: Alternative Perspectives and Schools. *Decision Support Systems, 3,* 243-265.

Ulvila, Jacob W., and Rex V. Brown. (1982). Decision Analysis Comes of Age. *Harvard Business Review* (September–October), 130–141.

Varis, O., and J. Kettunen. (1988). David Influence Diagram Processing System in Environmental Management. *Environmental Software, 3*(2), 81–84.

von Winterfeldt, Detlof. (1988). User-Model Interaction in Decision Support Systems for Risk Management. *Annals of Operations Research, 16,* 185–198.

von Winterfeldt, Detlof, and Ward Edwards. (1986). *Decision Analysis and Behavioral Research.* Cambridge: Cambridge University Press.

Williams, Adrian J. (1986). Decision Analysis for Computer Strategy Planning. In G. Mitra (ed.), *Computer Assisted Decision Making.* Amsterdam: North-Holland.

# Part Three

# Spreadsheet-based Software

The essence of decision-aiding software that is based on spreadsheets and multicriteria decision making (MCDM) is to have (1) the goals to be achieved on the columns, (2) the alternatives available for achieving them on the rows, (3) the relations between goals and alternatives in the cells, (4) an overall total for each alternative at the far right, and (5) the capability for quickly determining the effects of changes in the inputs on those overall totals.

That type of decision-aiding software can come in various forms. One way of distinguishing between the forms is in how they handle the basic criteria for comparing software packages mentioned in the Introduction to Part One of this book. Other less important ways of classifying spreadsheet-based software might be in terms of the brand name of the spreadsheets used, such as Lotus 1-2-3, Quattro, SuperCalc, VisiCalc, Framework, and Excel.

On the matter of multiple dimensions on multiple goals, a frequent approach is to measure all the goals on a common scale—for example, the 1, 3, 5, 7, and 9 scale used by Thomas Saaty in his analytic hierarchy system, the 0–100 scale used in LightYear and some other commercial packages, or the 1–5 scale used in P/G% drawing upon the scale theory developed by Rensis Likert. Those approaches, however, waste useful information if measurement is available indicating how many dollars each alternative costs or how many hours each alternative takes. The P/G% system is one of the few that allows diverse measures to be preserved by handling the multidimensionality through raw score increments, raw score weights, and part/whole percentages. The percentaging approach converts the miles, hours, dollars, and other measures into percentages of the maximum obtainable, the total obtainable, or some other percentage base that provides for a norming across diverse goals.

On the matter of missing information, a frequent approach is to seek the missing information, although doing so may be unnecessarily expensive. An alternative is to insert an average score, which may be unnecessarily invalid. An increasingly frequent approach is to use a variation on

what-if analysis, whereby the user experiments with different relation scores, goal weights, or other missing items to see the effects if the unknown variable were scored in various ways. That sounds sophisticated and is a big selling point of Lotus 1-2-3 and other commercial spreadsheets. It is better, however, to try to arrive at a set of break-even, threshold, critical, or other tie-causing scores above which one alternative is the winning one and below which another alternative would win. If, for example, the threshold value of a missing item is 6, then the user is informed that any number above 6 will enable the tentative first-place winner to retain first place, and any number below 6 will convert the second-place alternative into the new first-place winner. That kind of information can be provided for all the inputs. One then no longer asks what is the true value of a missing item. Instead, one asks the easier question of whether the true value is likely to be above or below the threshold value of 6 (or whatever else the threshold value might be). Variations on that kind of threshold analysis can apply to two, three, or more missing items simultaneously.

On the matter of allocation of money, time, people, or other resources to places, activities, or other objects, the traditional approach tends to be a highly subjective holistic perspective in which the goals to be achieved are only implicit. At the other extreme is the perspective of linear, nonlinear, or other forms of mathematical programming in which the only goals are those that are highly measurable so that equations and inequalities can be worked with. Spreadsheet software with an MCDM base (rather than a linear programming base) can enable a user who is not mathematically oriented to be able to deal with goals and relation scores, while at the same time the system can implicitly satisfy the rules of classical calculus optimization.

This is true of the part/whole percentaging system where one allocates to each budget category in proportion to how well it does on a weighted sum of their relations with explicit goals, where the relation scores can be on a scale as simple as a 1–5 scale. The system uses the ratios between such relation scores for different budget categories as proxies for the ratios between nonlinear elasticity coefficients. Such coefficients are virtually impossible to obtain directly given the nonavailability of data and the inability to control for confounding factors. The system is capable of dealing with diminishing returns whereby the best alternative receives the highest allocation but not 100 percent of the resources. At the same time, this nonlinear system does not get stuck in nonoptimum ruts since the system provides analytic solutions rather than wild reiterative guessing.

On the matter of satisfying multiple constraints, especially conflicting constraints, the traditional approach is to provide for some kind of compromise whereby each constraint may be partly violated or less important constraints might be completely violated. At the opposite extreme is the management science/operations research (MS/OR) approach of simply saying there is no solution if there are conflicting constraints. Spreadsheet software with an MCDM base helps facilitate the

finding of solutions where all the conflicting constraints can be simultaneously satisfied. One way it can do so is by clarifying exactly how much the budget needs to increase so that all the constraints will be satisfied. Another way is by clarifying how much the efficiency of each alternative has to improve on each goal in order to satisfy all the constraints without increasing the budget. A third way is by showing the combinations of budget increases and efficiency improvements that can simultaneously satisfy all the constraints. The MCDM spreadsheet approach can also clarify how new alternatives or new combinations can provide superoptimum solutions whereby all major constraints or viewpoints exceed their best initial expectations. The software does that by facilitating trial and error, by clarifying the characteristics of superoptimum solutions, and by enabling one to keep better track of the optimizing analysis when there may be many goals and many alternatives present.

On the matter of making predictions of the effects of alternatives on goals, the traditional perspective tends to be rather subjective and speculative. The MS/OR perspective looks technically competent with its use of multiple regression analysis, sophisticated time series, and other quantitative forecasting techniques. Those techniques, however, tend to ignore important predictive criteria that are not highly measurable. They also tend to be at the mercy of reciprocal causation, spurious causation, and interaction factors. The scores one inserts into the cells of an MCDM spreadsheet tend to rely more on common knowledge and deduced relations from known facts or reasonable premises. As with prescriptive analysis, the predictive analysis of MCDM spreadsheet software facilitates trial and error in order to arrive at a more valid and simpler predictive decision-rule by experimenting with different predictive criteria, weights, measurement units, and other inputs.

On the matter of simplicity, traditional lay approaches to decision making may be overly simple. Often they involve only one alternative, as in a go/no-go situation, and only one criterion, business profit. The decision then reduces to whether there is a positive or negative relation between the alternative and the criterion, frequently ignoring other alternatives, other criteria, constraints, and other methods of analysis besides dichotomous choice. At the other extreme is the overly complex MS/OR perspective, which may also have only a single objective function and a go/no-go alternative, but they are processed by way of elaborate models from mathematical programming, four-cell payoff matrices, decision trees, and network diagrams. The MCDM spreadsheet combines the validity of recognizing multiple alternatives and criteria with a simplicity that lay users can understand. A decision analysis table can be grasped by people with reasonable common sense and no technical background in mathematics, statistics, operations research, management science, or related fields.

Although the MCDM-based spreadsheet approach may have many advantages on an abstract level, there may be many situations where traditional lay approaches or complicated MS/OR approaches are more applicable. The traditional lay approach of the chicken crossing the road

usually works fine. One would not expect either chickens or people to do an MCDM spreadsheet analysis to decide whether or when to cross the street. That problem has been handled reasonably well ever since there were streets. It can be improved upon by looking both ways but not necessarily by making use of decision-aiding software. The problem is too simple, too frequent, too well done already, and not much is usually at stake. If one makes the mistake of not crossing when one could have gotten across, one can still cross two minutes later. There is not only one chance. If one makes the mistake of crossing when it is premature to do so, one can generally scurry back to the curb. A majority of all decisions are made by such holistic gut reactions.

Similarly, if an engineer is faced with a problem of how to build a bridge that will satisfy a lot of goals like safety, inexpensiveness, and wideness for carrying lots of cars, then a mathematical approach may be more relevant than a spreadsheet matrix. The mathematical approach may involve a form of linear or nonlinear programming that will take into consideration budget constraints, safety constraints, and car speed constraints, and not just goals of saving money, lives, and time. MS/OR models work especially well when many different kinds of constraints are present that can be quantified in the form of a series of inequalities. Trying to work with such constraints using MCDM spreadsheet perspectives involves too much trial and error, which may result in causing one to think one has arrived at an optimum solution only because one has put in a lot of time trying out nonoptimum alternatives.

The key problem in this context is that people in business may tend wrongly to emulate the people in engineering in seeking to find profit-maximizing equations. Worse than that, people in public policy may wrongly seek to emulate both the engineers and the quantitative business economists in trying to find equations for dealing with problems of free speech, equal treatment under law, fair procedure in criminal justice, and other such public policy problems. In those areas the MCDM spreadsheet perspective is at its best given its ability to deal with multiple dimensions, missing information, resource allocation, conflicting constraints, subjective prediction, and the need for simplicity in drawing and presenting conclusions.

# 6

# Spreadsheet-based Decision Support

STEVEN SONKA and MICHAEL HUDSON

Using computer technology to enhance the decision maker's ability to identify, evaluate, and implement decisions has long been a goal of computer scientists and decision makers. Through the 1950s, 1960s, and 1970s, tremendous strides were made in the business use of computers as computer capabilities expanded and costs declined. During this period, it became commonplace for large corporations to own powerful mainframe computers and to devote extensive human resources to the support of those tools.

Despite these advances, only small steps were made toward achieving the visionary goal of unlocking individual decision maker creativity through computer use. Because of the high cost and specialized skills needed to operate mainframe computers, the use of these tools was dominated by data processing and information management activities. Although using computers to manage payrolls, monitor inventory levels, and prepare routine financial statements can improve business efficiency, the gains tend to arise from cost reductions rather than advances in manager productivity. Further, the high acquisition and support costs of the mainframe computer preclude their extensive use in small and medium-sized firms, as well as by individuals.

During the latter portion of the 1970s, the personal computer revolution burst into being. Suddenly the financial barriers separating the individual decision maker and computer capabilities were effectively destroyed. For much less than the price of a personal automobile, individuals could acquire microcomputers with significant computational capacity. And as personal computers advanced in capacity and declined in cost in the 1980s, even more effective tools were made available.

But significant barriers still remained, impeding creative decision-making

applications of the computer, especially by individuals and managers who were either too busy or not inclined to experiment with computers. Effective software was soon recognized as a major barrier. Potential users were faced with the choice of purchasing off-the-shelf packages or developing their own applications software. Adequate software packages for data processing-oriented activities, especially general ledger accounting, soon became available. Data processing with the microcomputer, however, delivers little more decision creativity than do the same activities performed with large computers. And although higher-level programming languages, such as BASIC or Pascal are easier to learn than earlier mainframe languages, their effective use requires extensive learning time, and their application is seldom intuitive to the casual user.

In the entrepreneurial world of the personal computer, such an unmet need did not exist long. General-purpose software packages soon became available. General-purpose spreadsheet and database packages promised that the nonprogrammer could use the personal computer to develop significant decision support system (DSS) capabilities. These DSSs could be sufficiently sophisticated to address important business problems. Further, the ease of use of general-purpose software implied that tailored DSSs could be developed. Tailoring of the DSS to accommodate the unique features of specific decision situations as well as the desires and needs of individual decision makers is critically important in moving to an environment where DSSs truly support creative decision processes.

Although these technological advances have presented individual decision makers with an unprecedented opportunity, much remains to be learned to employ most effectively these powerful tools to aid decision making. This chapter draws upon a very unusual educational experience to gain insights as to both the potential for DSS development offered by these tools and the significant impediments that still exist. Specifically it addresses the following questions:

1. Can useful DSSs, applied to nontrivial business problems, be developed by nonprogrammers using a general-purpose software package such as Lotus 1-2-3?
2. Can such spreadsheet-based tools be developed so as to overcome psychologically based limitations of human decision making, such as those arising from memory capacity constraints or from our weaknesses in addressing the uncertain nature of business decision situations?

## EDUCATING STUDENTS ABOUT SPREADSHEET-BASED DSSs

Because of burgeoning student interest in microcomputers and to investigate the potential for DSS development, an experimental class was started at the University of Illinois at Urbana-Champaign in the spring of 1986. The

class, titled Decision Support Systems in Agriculture, took an aggressive posture as to the most effective means to advance student understanding of DSSs and the microcomputer technology. Instead of just reviewing systems available, each student was charged with developing a spreadsheet-based DSS that addressed a realistic business decision problem and incorporated relevant decision concepts from the rapidly advancing field of decision theory. This philosophy resulted in an educational experience in the use and application of microcomputers.

In the four times that the course has been offered, over eighty students have participated in the class. These students were upperclass undergraduates or master's students interested in management of agricultural firms. Although a few plan to be directly involved in farm production, the majority will pursue careers in the large and diverse food and agribusiness sector. Students in the class have taken positions as loan officers, in sales and marketing, and as merchandisers involved with commodity trading. Direct development of computer software has rarely been a career goal of a student.

Introductory computer competence and familiarity with spreadsheets is a prerequisite for entry into the course. Prior to the class, the typical student is comfortable entering data into spreadsheet programs, constructing simple formulas, and performing routine file maintenance and printing activities with a spreadsheet. If any prior coursework in programming had been taken, it would have been limited to an introductory course in programming using a language such as Pascal or BASIC.

The course structure is divided equally between gaining the capability to employ advanced spreadsheet features (macros, menus, and database commands) and developing an understanding of relevant problem solving and decision theory concepts. For the latter goal a diverse set of readings from business and psychology literatures is reviewed and discussed. As a term project, each student develops a prototype DSS that addresses a realistic business situation and illustrates relevant aspects of decision making within the framework of the DSS.

## PROBLEM SOLVING AND DECISION THEORY CONCEPTS

Identification of realistic decision situations can often be a problem for college students; however, because all of the students are focusing on agricultural careers, their access to decision makers and their familiarity with typical agribusiness problems is improved. In addition, many of the students are employed part time or have an involvement with a family-operated business. In fact, nearly 50 percent of the projects developed have been created for a specific decision maker rather than for a hypothetical situation. Examination of the types of problems addressed may give an indication of the likely uses of spreadsheet-based DSSs in the business world.

### Types of Problems

Problem settings can be categorized as strategic, tactical, or operational in nature. The spreadsheet DSSs developed have had a significant representation from all three categories. DSSs devoted to strategic choices have considered the desirability of major capital asset purchases, start-up of new business ventures, and investigation of the performance of specific subunits within a business. Tactical decisions evaluated have included income tax planning, choice of financing options, and government farm program participation. DSSs addressing tactical and strategic problems were designed for relatively unstructured decision situations. A wide range of operational decisions has been evaluated, including comparison of production alternatives, grain marketing options, and alternative purchasing sources for inputs. These operational DSSs are typically employed in structured decision settings.

The majority of the DSSs have included a financial analysis among alternatives. These utilize projection methods to perform what-if evaluations. A number of these programs have included a significant data query capability as well. For example, a DSS designed for an agricultural consulting firm assists in monitoring employee hours but also provides the capability to perform numerous sorting options. With this capability, the project manager can compare planned to actual performance by project, by client, or by type of activity.

### Decision Theory Concepts

Over the past few decades, there has been a considerable advance in our understanding of decision-making processes of individuals. Although a subject of debate between some economists and psychologists, it is generally conceded that the pure assumptions of the completely rational economic person are implausible (Simon 1987; Arrow 1982). Rather, the search for information is costly, decision-maker time is limited, and their attention often is fragmented. DSSs exist to improve the decision making of individual decision makers. To do so requires that such programs explicitly consider human limitations and constraints to decision making.

One of the goals of the course described was to determine if decision theory concepts could be incorporated into spreadsheet-based DSSs. Three types of concepts have been considered: the first deals with the physical operation and use of spreadsheets, the second arises from the limited memory capacity of humans, and the third relates to the difficulty that decision makers have in assessing situations in which significant uncertainty exists.

When introduced, spreadsheets immediately were welcomed because of their intuitive nature (Sonka 1983). Menus were available to assist the user by summarizing a series of commands into a few keystrokes, and their use of

words as prompts allowed the infrequent user to recall commands rather than having to memorize them. However, as spreadsheets were applied to increasingly sophisticated problems, a number of difficulties emerged. Cursor movement becomes difficult and tedious as the spreadsheet grows larger. Further, the letter/number combination of cell coordinates is not particularly intuitive, nor is it easy to remember.

To overcome these difficulties, spreadsheet-based DSSs can be designed to be user friendly through extensive menus. These menus limit the need to scroll across the spreadsheet with the cursor and allow the user to perform complex operations (such as printing a set of reports) with minimal use of keystrokes.

Although often thought of as the ultimate computer, the human mind has limits in the amount of information it can process and remember. Effective DSS design should assist the user in overcoming these limitations. Davis and Olson (1985) catalog a substantial list of such limitations, among them, information overload, the need for feedback, filtering, and the process of anchoring and adjustment. Information overload, as its name implies, refers to the decision maker's ability to comprehend and process an excessive amount of information. Report format is an important aspect of overload. For example, a manager accustomed to evaluating a specific form of financial statement may find information presented in that form easy to assimilate, although the report may appear cluttered to others.

To feel comfortable with the technology, users need feedback as they use computers. In DSS design, construction of compact input forms so that the user attains a feeling of accomplishment by completing separate sections is one means of providing feedback. At times, spreadsheets need to perform a number of calculations or manipulations, and in doing so the user may perceive a loss of control. Spreadsheet-based DSSs should anticipate these situations and provide messages on the screen to reassure users that normal processes are occurring.

Filtering is a process by which large amounts of data are reduced to a more useful form. The definition of useful is critical in this summarization. Therefore, DSS developers need to understand the information needs of the user. This aspect is one of the major potential benefits that spreadsheet-based DSSs offer because in many cases the DSS developer can also be a user of the information.

Anchoring and adjustment refers to the process by which decision makers evaluate information. An estimate of next year's net income, for example, is of little value unless the user can place that number into a business context. Decision makers automatically attempt to make a comparison between that estimated income and last year's income. In this case, last year's income is the anchor point, and the manager considers the estimated income as an adjustment from that anchor. DSSs may significantly assist decision making if they can provide appropriate and accurate anchor points for the user.

Most significant business decisions involve uncertain outcomes, and managers must make decisions without a guaranteed outcome. Unfortunately, it has been widely documented that individuals are not, in a practical sense, good statisticians and tend not to follow rules of logical decision making when outcomes are uncertain. Kahneman and Tversky (1979) have shown that problem framing is a critical part of the decision-making process. Their prospect theory approach suggests that design of DSSs must pay particular attention to whether the manner in which the problem is framed will affect the user's response to its information.

Chance events can dramatically affect outcomes of nearly every project. Yet decision makers have difficulty in separately identifying the role of chance from that of performance in evaluating outcomes. DSSs are widely recognized for having the ability to demonstrate the effect of chance events on projected outcomes. Further, DSSs should also be effective in helping to overcome the hindsight bias that can distort evaluation of outcomes.

## EXAMPLE DSSs

A large number of prototype DSSs have been developed in the Decision Support Systems in Agriculture class. Here three specific spreadsheet-based DSSs will be briefly reviewed. These three were selected to illustrate spreadsheet-based DSS application across a range of decision situations. The first of the three will be discussed in greater detail, to illustrate the potential for user-created menus to assist the decision maker. Discussion of the two remaining DSSs will be limited to an examination of their purposes and the means by which they relate to some of the decision concepts noted above.

### CAPP's DSS

A manager of a farmer's cooperative was considering alternative means to expand the profitability of the enterprise. The firm comprises several subunits, of which retail and wholesale sales of fertilizer are major factors. Expanding the retail sales component seemed a likely candidate for success, but numerous uncertainties existed. A major limitation was that the firm did not have adequately detailed cost records to assess accurately the independent profitability of the retail fertilizer operation. The CAPP's RFD (cost allocation and projected profitability of the retail fertilizer division) DSS was developed to assist that manager in this assessment of strategic options. In particular the manager wanted a tool to examine some of the implications of expanding retail fertilizer sales prior to conducting an extensive and expensive analysis of that option.

CAPP's RFD allows the manager to utilize existing data, make minimal assumptions, and observe the impact of those assumptions on the expected profitability of fertilizer sales. Because the manager involved had minimal

computer background, the DSS needed to be extremely easy to use. This goal was accomplished through extensive use of specialized menus created using the Lotus 1-2-3 macro and command language capability.

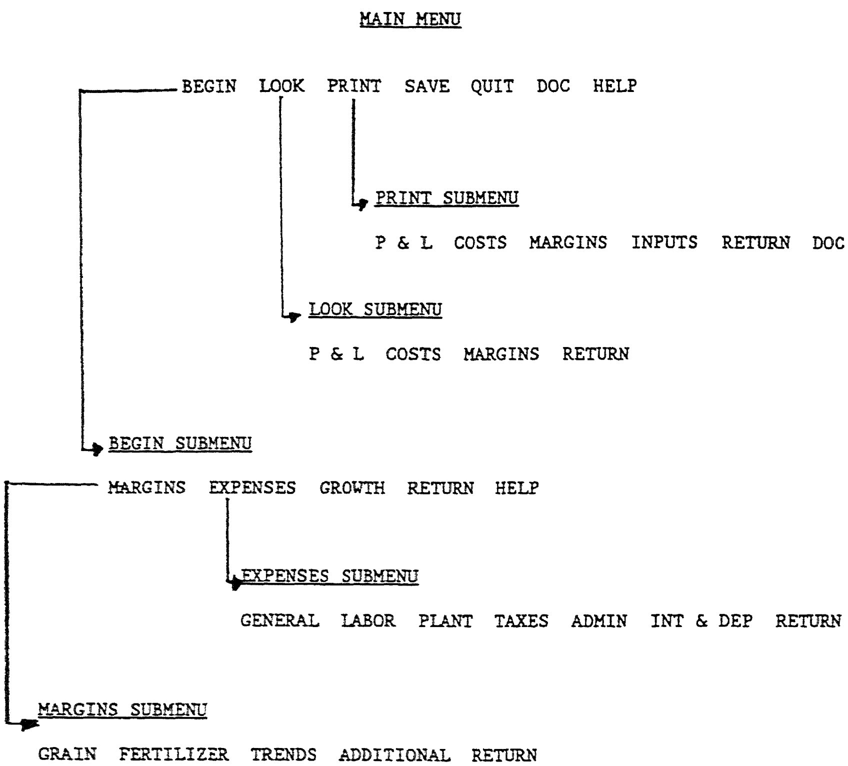
Figure 6.1 presents the main menu that the user sees when initiating the CAPP's RFD program. The words listed as "menu options to choose among" in the figure are the options that the user sees in the panel area of the Lotus 1-2-3 screen. These options operate in an identical fashion to Lotus 1-2-3's general menu options; the user can invoke an operation by moving the cursor to be positioned over an option and hitting the enter key or by typing the first letter of that option (e.g., *p* for *print*). To allow the user to understand better the choices available, the messages listed under "explanation of menu options" are shown in the window area of the screen. (The window area is the main part of the screen when one views a Lotus 1-2-3 spreadsheet.) In addition to providing additional information, presenting the menu option explanations in the window area ensures that the user is not distracted or confused by extraneous information that may appear on the screen.

After selecting a menu option, the user may immediately proceed to an active worksheet area (moving directly to a help screen with additional information) or is presented with another set of options within a submenu. Figure 6.2 presents a schematic of the significant submenus incorporated within CAPP's RFD. (Opportunities to back out of the save and quit options are available but are not shown here.) After selecting the begin option, for example, the appropriate submenu appears. Here the user can choose to input

**Figure 6.1**
**Example of Main Menu Screen of the CAPP's RFD Spreadsheet DSS**

```
                         Menu options to choose among

BEGIN      LOOK       PRINT      SAVE       QUIT       DOC        HELP



                         Explanation of menu options

           BEGIN using CAPPs RFD:  Input data.

           LOOK at results on screen.

           PRINT results.

           SAVE worksheet.

           QUIT using CAPPs RFD.

           DOCumentation.

           HELP  directions for using CAPPs RFD.
```

**Figure 6.2**
**Complete Menu Structure for the CAPP's RFD Spreadsheet DSS**




data associated with margins on the firm's operations, expenses, projections for growth, return to the main menu, or examine a help screen. If either the margins or expenses options are chosen, submenus with a number of additional choices appear.

With the menu structure shown in Figure 6.2, CAPP's RFD is a completely menu-driven program. Figure 6.2 illustrates the level of complexity for the DSSs developed in the Decision Support Systems in Agriculture class. This level also is representative of that needed to attack meaningful decision problems with spreadsheet-based DSSs.

CAPP's RFD prepares a four-year projection of financial performance. Table 6.1 shows the key base data needed on margins for the firm. Here the base year is shown as 1987. (The data shown are completely fictitious to preserve the financial integrity of the firm involved in this DSS development.) To enter or alter a number, the user moves the cursor to the appropriate cell and types in the desired value. To aid the user, cursor movement is restricted to cells in which values should be entered. In CAPP's RFD, for

**Table 6.1**
**Screen to Input Base Year Margins**

```
          RETAIL FERTILIZER REVENUE

Input MARGINS and TONNAGE incurred in          1987
for each item.  Press ENTER when finished.
```

| Fertilizer | Margin per Ton | Tonnage Sold |
|---|---|---|
| Dry Fertilizer | $4.50 | 10,000.00 tons |
| Liquid Fertilizer | 6.00 | 1,500.00 tons |
| Anhydrous | 40.00 | 10.00 tons |
| Limestone | 3.00 | 600.00 tons |
| Spreading & Delivery | 2,500.00 | |
| Misc. (total) | $10,000.00 | |

example, the cursor can only move to the six cells under the "Margin" column and the four cells under the "Tonnage Sold" column.

A major problem limiting the firm's strategy evaluation was lack of detailed cost allocation data. Table 6.2 presents the table in which general allocation proportions are entered. This table appears after the user selects the GENERAL option under the EXPENSES submenu (Figure 6.2). Although the user does not have precise allocation data, use of the proportions approach in Table 6.2 allows the user to conduct preliminary evaluations with-

**Table 6.2**
**Screen to Input General Allocation Factors**

```
            GENERAL ALLOCATION SCHEDULE

Enter the PROPORTION of each expense category you wish to have
allocated to the retail fertilizer division.  You will have a chance
later to make specific allocations if you wish.  ENTER to return.
```

| Category | Proportion |
|---|---|
| Management & Labor | 0.70 |
| Plant Expenses | 0.60 |
| Taxes, Insurance, Leases | 0.65 |
| General Administrative | 0.75 |
| Interest & Depreciation | 0.50 |

out undue expense to acquire more precise data. These proportions are easily changed so that the manager can observe where data shortcomings are most significant. (Again, the cursor is constrained to moving within the five cells under the proportion column.)

Table 6.3 illustrates the format of the tables within which specific expense data are entered. (This table is reached by selecting the LABOR option within the EXPENSES submenu in Figure 6.2). Expenses for both the retail and wholesale fertilizer divisions are fairly well known by the firm's manager, and these values are to be entered under the "Total Expense" column. The data in the "Proportions" column are automatically transferred from the general allocation schedule (Table 6.2) unless the user overrides that allocation for a specific expense category. To illustrate, the 0.50 proportions for the managers' salaries and office salaries categories have been manually entered, whereas the 0.70 proportions for the other categories were transferred from the management and labor category of Table 6.2.

The major output report of CAPP's RFD is a five-year profit-and-loss statement (Table 6.4). The first data column presents actual profit data for 1987. This serves as an anchor point by which the user can evaluate the implications of the four-year projection estimates shown in the remaining columns. The volume data at the bottom of the figure serve as an alternative reference point, which may be more meaningful for board members who may not be comfortable with financial data only. The profit-and-loss statement shown in Table 6.4 is somewhat crowded and suffers to some extent

**Table 6.3**
**Screen to Input Specific Cost Data**

MANAGEMENT AND LABOR COSTS

Enter TOTAL EXPENSE expected or incurred and the PROPORTION to be allocated to retail fertilizer in 1987; ENTER when finished.

| | Total Expense | Proportion |
|---|---|---|
| Managers Salaries | $30,000.00 | 0.50 |
| Office Salaries | 2,000.00 | 0.50 |
| Plant Salaries | 15,000.00 | 0.70 |
| Payroll Taxes | 1,500.00 | 0.70 |
| Employees' Benefits | 1,000.00 | 0.70 |
| Employee Education | 200.00 | 0.70 |
| Sales Commissions | 0.00 | 0.70 |
| Pension Fund Account | 1,500.00 | 0.70 |
| Miscellaneous | 0.00 | 0.70 |

**Table 6.4**
**Example of Major Output Report**

Profit and Loss Statement

| | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|
| Margins | | | | | |
| Dry Fertilizer ...... | $45,000.00 | $47,891.25 | $50,720.18 | $53,487.73 | $56,194.87 |
| Liquid Fertilizer ... | 9,000.00 | 12,120.00 | 15,301.50 | 18,545.42 | 21,852.68 |
| Anhydrous .......... | 400.00 | 4,400.00 | 8,400.00 | 12,400.00 | 16,400.00 |
| Limestone .......... | 1,800.00 | 3,267.00 | 4,704.48 | 6,112.88 | 7,492.65 |
| Service & Misc. ..... | 12,500.00 | 12,700.00 | 13,050.00 | 13,450.00 | 14,000.00 |
| Total Gross Margin .... | $68,700.00 | $80,378.25 | $92,176.16 | $103,996.03 | $115,940.20 |
| Expenses | | | | | |
| Management & Labor .. | $35,840.00 | $36,656.80 | $37,739.94 | $38,744.73 | $39,619.63 |
| Plant Expenses ...... | 15,300.00 | 15,606.00 | 15,918.12 | 16,236.48 | 16,561.21 |
| Taxes, Insurance & Leases ........... | 1,820.00 | 1,856.40 | 1,893.53 | 1,931.40 | 1,970.03 |
| Gen. Administrative . | 2,572.50 | 2,623.95 | 2,676.43 | 2,729.96 | 2,784.56 |
| Depreciation ........ | 5,000.00 | 5,100.00 | 5,202.00 | 5,306.04 | 5,412.16 |
| Interest ........... | 6,250.00 | 6,375.00 | 6,502.50 | 6,632.55 | 6,765.20 |
| Total Retail Expense .. | $66,782.50 | $68,218.15 | $69,932.51 | $71,581.16 | $73,112.79 |
| NET INCOME ....... | $ 1,917.50 | $12,160.10 | $22,243.64 | $32,414.87 | $42,827.41 |

| Total Volumes (tons) | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|
| Dry Fertilizer ....... | 10,000 | 10,750 | 11,500 | 12,250 | 13,000 |
| Liquid Fertilizer .... | 1,500 | 2,000 | 2,500 | 3,000 | 3,500 |
| Anhydrous ............ | 10 | 110 | 210 | 310 | 410 |
| Limestone ............ | 600 | 1,100 | 1,600 | 2,100 | 2,600 |
| Total Tonnage .......... | 12,110 | 13,960 | 15,810 | 17,660 | 19,510 |

from information overload. This format is, however, the standard for the firm, and, presumably, managers are accustomed to evaluating information in this form.

Even if complete historic cost data were available, any four-year projection involves considerable uncertainty. To provide the decision maker a means to evaluate the effect of alternative assumptions, a number of sensitivity analysis tables are provided. Table 6.5 displays one such table, illustrating the impact on expected net income of alternative margins for dry fertilizer products. The base margin of $4.50 was entered by the user in the margins table (Table 6.1). If a differing base margin is entered, the margin values in the sensitivity table are altered and the table recalculated.

CAPP's RFD is an example of a spreadsheet-based DSS that can be applied to the very unstructured problem of determining a firm's future strategy. Its menu-driven structure, as well as that of the two DSSs yet to be discussed, allows the user to interface with the DSS and overcome some of the user-unfriendly features of spreadsheets. The program's structure allows the user to consider alternative cost allocation options rapidly and in so do-

**Table 6.5**
**Example of Sensitivity Analysis Capabilities within CAPP's RFD**

SENSITIVITY ANALYSIS OF MARGINS
FOR DRY FERTILIZER

This table shows expected net incomes from varying margin levels, in each of the respective years. ENTER when finished.

| Percent of current | Margin | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|
| 85% | $3.82 | (4,832) | 4,976 | 14,635 | 24,391 | 34,398 |
| 90 | 4.05 | (2,582) | 7,370 | 17,171 | 27,066 | 37,207 |
| 95 | 4.27 | (332) | 9,765 | 19,707 | 29,740 | 40,017 |
| 100 | 4.50 | 1,917 | 12,160 | 22,243 | 32,414 | 42,827 |
| 105 | 4.73 | 4,167 | 14,554 | 24,779 | 35,089 | 45,637 |
| 110 | 4.95 | 6,417 | 16,949 | 27,315 | 37,763 | 48,446 |

ing provides an effective tool to aid the decision maker in framing the problem situation. Considerable filtering occurs in collapsing numerous types of input into a few focused output reports.

## MKTPLANNER DSS

The typical cash grain producer physically harvests the crop during a one- or two-month period. That commodity can then be stored for several months, allowing the producer to select the most appropriate times to deliver the crop to market. Development of the marketing plan, therefore, is one of the major decisions faced each year. In making this decision, the producer must consider potential price moves (which can be quite substantial), as well as the need for cash to operate the business until another crop is harvested. The MKTPLANNER DSS was designed for a moderate-sized cash grain operation in the Midwest.

The major output report of this DSS is a monthly cash flow statement. This financial document is widely used by producers and is of special interest to agricultural lenders as they evaluate the creditworthiness of potential borrowers. The typical farm financial statement is composed of three segments:

1. A listing of receipts expected from the firm's operations.
2. A listing of expenditures for the coming twelve months.
3. A financing section where cash shortages from operations can be offset by borrowing and cash surpluses used to repay obligations.

The typical monthly cash flow statement epitomizes the problems of information overload. For DSS developers, a more serious problem is that the cash flow statement does not integrate well with the decisions that the manager makes. Decision makers often are more comfortable thinking in terms of physical units and prices (or margins) than they are in terms of aggregate cash data. Therefore, the cash flow statement may not be very meaningful for the decision maker. This problem is not limited to agricultural producers and is especially relevant for managers of small businesses.

The MKTPLANNER DSS requires standard business information as input. Compact, user-friendly input screens, such as shown for CAPP's RFD, are used to acquire this information. The major item separating the MKTPLANNER DSS from a typical cash flow program is the student developer's inclusion of a decision-making table. Table 6.6 illustrates the format of the table for the first five months of the year.

The manager for whom MKTPLANNER was created was primarily interested in a tool to consider sales options in the context of financing needs for each option. Therefore the decision-making table allows the user to alter the planned timing and amount of grain sales and observe the effect on the firm's monthly cash position. Further, financing alternatives, such as bor-

**Table 6.6**
**Example of the Decision-Making Table of MKTPLANNER**

| | MONTHLY | | DECISIONS | | |
|---|---|---|---|---|---|
| | JAN | FEB | MARCH | APR | MAY |
| Begining Cash Balance | 500 | 4,360 | 1,220 | 480 | 701 |
| *Corn in Storage* | *16,000* | *16,000* | *4,500* | *3,500* | *1,000* |
| *Corn in Storage to Sell* | *4,000* | *0* | *11,500* | *1,000* | *2,500* |
| *Soybeans in Storage* | *0* | *0* | *0* | *0* | *0* |
| *Soybeans in Storage to Sell* | | | | | |
| *Wheat in Storage* | *0* | *0* | *0* | *0* | *0* |
| *Wheat in Storage to Sell* | | | | | |
| TOTAL RECEIPTS: | 8,500 | 4,360 | 24,220 | 2,480 | 5,701 |
| TOTAL EXPENDITURES: | 3,765 | 2,765 | 8,365 | 18,529 | 4,429 |
| Operating Loan Balance | 45,000 | 45,000 | 30,000 | 30,000 | 30,000 |
| *Repay Operating Loan* | *0* | | *15,000* | | |
| Savings Balance | 217 | 235 | 254 | 275 | 298 |
| *+/- from Savings* | *0* | *0* | *0* | *0* | *0* |
| *Operating Loan* | *0* | *0* | *0* | *0* | *0* |
| *Long Term Loan* | *0* | *0* | *0* | *0* | *0* |
| ENDING BALANCE | 4,360 | 1,220 | 480 | 701 | 1,022 |

rowing additional operating funds or debt repayment, are also entered within this table.

In Table 6.6, the rows in italics are areas where the user can enter marketing or finance-related decisions. The upper six shaded rows refer to marketing choices. The user is informed as to the amount of each crop in storage at the start of each month and then indicates the amount of desired sales during the month. The DSS automatically computes the revenue from those sales in determining the firm's planned net cash position and calculates the amount remaining for sale. For example, in Table 6.6, the user plans to sell 4,000 bushels during January, which will leave 16,000 bushels for sale. The lower four shaded rows refer to financing decisions available to the user. The plan shown in Table 6.6 involves repaying $15,000 of operating debt in March, taking out a $17,000 long-term note in April, no additional short-term borrowing, and no inflows or outflows to savings. (Repayment of long-term notes is considered a fixed expenditure and is included in the expenditure section of the cash flow.)

The table converts the relatively sterile cash flow preparation process into a dynamic decision-making framework. As the user alters planning marketing or financial actions, the repercussions of those actions are immediately registered. Because many agricultural producers are concerned with cash flow issues, the ending cash balance line of Table 6.6 is a vivid anchor point for their decision making. The twelve-month nature of the monthly cash flow requires that the table be somewhat unwieldy. The five months shown are all that can be seen on the computer screen at one time. As the user moves to later months in the year, he or she can "scroll" to see the additional months. Both the column and row titles remain on the screen at all times, but this process is awkward. That problem is dictated by the decision maker's choice of detail, however. For example, a quarterly version of the same statement would be much more user friendly if a particular user was comfortable with that level of information.

### LOANMON DSS

The third DSS is also concerned with the cash flow position of the agricultural producer but from the perspective of the lender, not the borrower. Traditionally, agricultural operating loans are made at the start of the calendar year, with fund disbursement and repayment occurring at several times during the year. Because of market and environmental uncertainties, however, the borrower's actual financial position can be dramatically different at the end of the year than it was expected to be. For borrowers known to be in marginal circumstances at the time the loan is initiated, it is routine practice to require that the borrower's actual cash position be reported to the lender monthly as the year progresses. Such reporting is a costly practice, and many borrowers resist this requirement.

As the year progresses, events may occur that markedly affect the financial position of a loan officer's clients. Droughts in the local region may reduce yield expectations, whereas droughts in competitor regions may raise price expectations. Political events, such as grain embargoes or announcements of new trade agreements, may substantially alter the market outlook. Although the loan officer has detailed financial projections data for each client, it is too costly to recalculate those projections manually for each borrower. The LOANMON DSS was created by a student with several years of experience as a loan officer. Its purpose is to allow the loan officer to alter a few key variables and observe the financial effect of those changes on the client portfolio. In particular, the DSS is designed to identify borrowers for whom the changed circumstance may imply difficulty in future loan repayment. Such forewarning would allow the borrower and the lender to consider contingency plans before the repayment problem became a crisis.

At the time of the loan application, expected values for a wide range of variables are obtained. These include expectations of:

- Prices and production for each commodity produced.
- Amounts of other sources of income.
- Cash operating expenses.
- Required debt repayment.
- Capital purchases.
- Withdrawals for family living.

These values are entered into the LOANMON DSS through input screens as for the previous two DSSs. At that time, the DSS is essentially a database of the loan officer's portfolio.

For each borrower, the loan officer determines a critical cash flow value at the time that the loan is made. This critical value represents a financial level at which the loan officer would feel the need to monitor that loan more closely. It does not necessarily mean that loan repayment is in jeopardy. Rather, it implies a financial level at which additional loan servicing may be required. This critical cash flow is a key to LOANMON's structure.

Understanding LOANMON may be aided by an example. Assume that market conditions have deteriorated since the start of the calendar when most loans were initiated and that the harvest price of corn has fallen from $2.50 to $2.00 per bushel. The loan officer would enter prices for all commodities representing these new market expectations. Based on these expectations, LOANMON recalculates cash flow projections for each borrower. Note, however, that the market prices used for each borrower are not necessarily those just entered. Instead, each borrower's original expected price is adjusted by the general change in market price that has occurred (a decline of 20 percent in this example). This allows individual differences in market-

ing ability, which were embedded in the original values, to be preserved but general changes in price level to be evaluated.

LOANMON has the capability to produce two major output reports. These reports list the original budgeted cash flow, the cash flow currently estimated, the critical cash flow value, and the difference between the currently estimated and the critical value cash flow. One of these reports will list all of the borrowers in the portfolio. The second lists only those borrowers on the watch list—those for whom the difference is negative between the currently estimated and the critical value cash flow. Table 6.7 presents an example of this second report for a hypothetical set of borrowers. In addition to the borrower list, the report contains a listing of the price assumptions used to prepare the analysis. These data can be invaluable in helping to explain the cash flow results to other officers of the financial institution or to the borrower.

LOANMON illustrates the use of a DSS in an operational, structured decision situation. In fact, the data input can be accomplished by a clerk and

**Table 6.7**
**Example of the Critical Value Cash Flow Report for LOANMON**

First Warmhearted Bank

Report of Farm Borrowers

Whose Projected Cash Flow is

Less Than Critical Value

| Name | Cash Flow Budgeted | Current Price Cash Flow | Cash Flow Critical Value | Difference |
|---|---|---|---|---|
| Greenup, Fred | 6,683 | 9,283 | 25,000 | (15,717) |
| Revere, Paul | 20,560 | (7,650) | 60,000 | (67,650) |
| Sodbuster, C. | 113,500 | (23,660) | 65,000 | (88,660) |
| White, York | 25,842 | (2,478) | 30,000 | (32,478) |

Price Assumptions

| | |
|---|---|
| Corn, $/bu. . . . . . . . . . . . . . | $2.37 |
| Beans, $/bu. . . . . . . . . . . . . . | $5,32 |
| Wheat, $/bu. . . . . . . . . . . . . . | $3.64 |
| Cattle, $/cwt. . . . . . . . . . . . . . | $53.20 |
| Hogs, $/cwt . . . . . . . . . . . . . . | $41.25 |

the watch list report delivered weekly throughout the year. If a dramatic event occurs, the process can be initiated quickly. The LOANMON DSS is a classic illustration of filtering. Considerable data are needed to perform the necessary calculations. However, only a few key output variables are presented to the decision maker and then only for borrowers for whom special attention may be needed.

## SUMMARY AND IMPLICATIONS

This chapter addressed the potential for development of spreadsheet-based decision support systems. Drawing upon several years of experience in supervising student-generated DSS prototypes, it focused on two interrelated questions:

1. Can useful DSSs, applied to nontrivial business problems, be developed by non-programmers using a general-purpose software package such as Lotus 1-2-3?
2. Can such spreadsheet-based tools be developed so as to overcome psychologically based limitations of human decision making?

In both cases, the evidence presented supports an affirmative response to these questions; however, important qualifications also are indicated.

The prototype DSSs shown here indicated that useful programs can be developed to investigate real business issues. The menu-driven nature of these prototypes, as illustrated for the CAPP's RFD example, results in programs that are easy to use. This ease of use is very important for the "non-computer-oriented," manager as well as in making the transactions costs of using the program much lower for the computer literate user. Spreadsheet-based DSSs, addressing realistic business problems, are not trivial undertakings. Although no formal reporting process has been in place, observation and discussion with the student developers suggest that forty to eighty hours of intense effort may be needed to reach the prototype stage outlined here, plus additional time for final modification and documentation. Although the payoff from use of these DSSs may be substantial, it is critically important that everyone involved in development understand the time costs potentially required.

Explicitly addressing decision-making concepts in DSS development seems a worthwhile endeavor. Although everyone wants user-friendly programs, we have little in the way of guidelines to use in creating such programs. To this point, the emphasis has been on interface features, such as menus or means to reduce keystroke requirements. These options are important, but the truly user-friendly program must deliver the information needed for decision making in a concise and effective manner. As illustrated in the three example DSSs, tailoring of DSS, for either specific decision situations or the needs of individual decision makers, is a major potential benefit of the spreadsheet-based approach.

## REFERENCES

Arrow, K. J. (1982). "Risk Perception in Psychology and Economics." *Economic Inquiry, 20,* 1–9.

Davis, G. B., and M. H. Olson. (1985). *Management Information Systems.* New York: McGraw-Hill.

Kahneman, D., and A. Tversky. (1979). "Prospect Theory: An Analysis of Decisions under Risk." *Econometrica, 47,* 263–291.

Simon, H. A. (1987). "Rationality in Psychology and Economics." In *Rational Choice.* Edited by R. M. Hogarth and R. W. Reder. Chicago: University of Chicago Press.

Sonka, S. T. (1983). *Computers in Farming.* New York: McGraw-Hill.

7

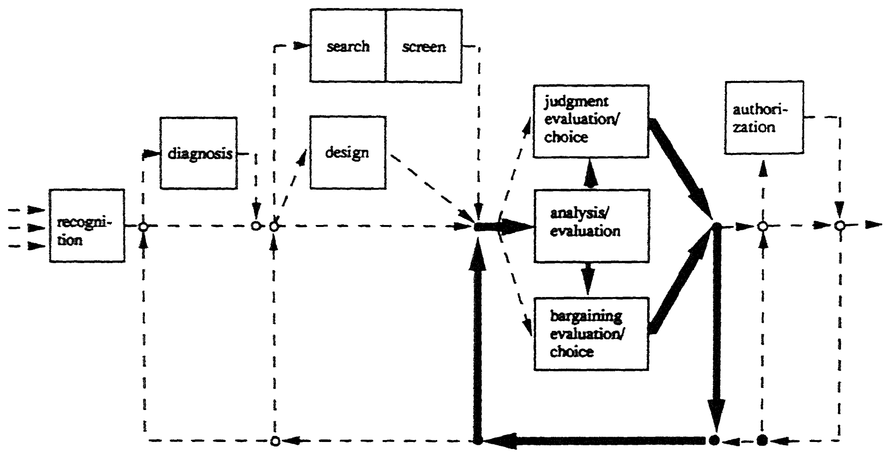
# A Spreadsheet System to Support the Decision-Making Process

RON JANSSEN

Decision support systems (DSS) can be defined as "interactive computer-based systems that help decision makers utilize data and models to solve unstructured problems" (Gorry & Scott Morton 1971). Although this definition is now more than twenty years old and although numerous competing definitions have been developed, this definition contains all the elements that are essential to the concept of decision support. "Interactive" and "computer-based" are essential features of DSS. By using a DSS, decision makers no longer communicate with models through an analyst but have direct access to available models and information. "Help the decision makers" highlights the point that decision makers as individuals are supported. "Utilize data and models" emphasizes that support is given by processing information.

Multiobjective decision support systems (MODSS) are a specific subcategory of DSS. An MODSS concentrates on the support of analysis/evaluation in a decision process (Figure 7.1) (Mintzberg, Raisinghani & Théorêt 1976). A MODSS includes formal methods such as multicriteria methods, graphic methods, and cost-benefit analysis combined with methods for problem definition and sensitivity analysis. In this way MODSS can support both the selection and the development phase of a decision process (Janssen 1992).

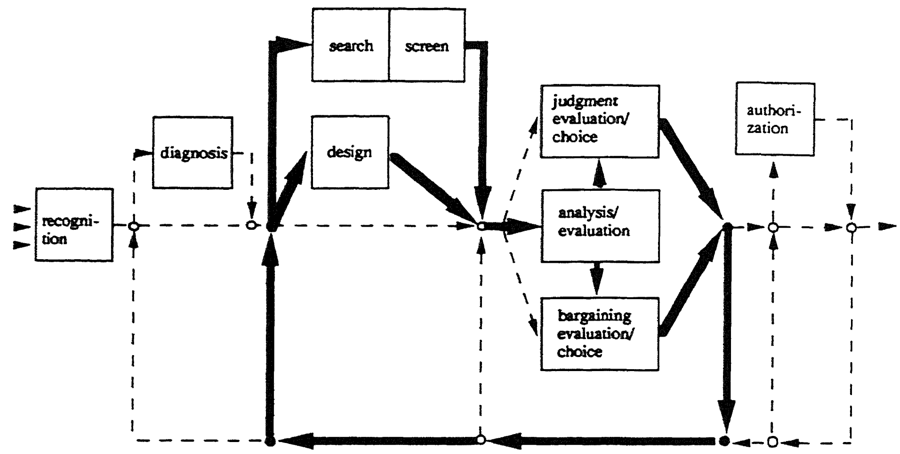
**Figure 7.1**
**Support of the Selection Phase**




The cycle that supports the selection phase is shown in Figure 7.1. In the first round of this cycle, the results of analysis/evaluation enter either judgment evaluation/choice or bargaining evaluation/choice. Results of this first round are fed back into analysis/evaluation and may lead to changes in priorities and assumptions. By cycling repetitively, the influence of priorities and assumptions can be analyzed. Mintzberg, Raisinghani and Théorêt (1976) qualify this type of cycle as a comprehension cycle.

The feedback cycle supporting the development phase is shown in Figure 7.2. In the first round of this cycle, the results of analysis/evaluation enter judgment evaluation/choice or bargaining evaluation/choice. If the results are unsatisfactory, which is to be expected in the first round, a feedback occurs to design (to alter existing alternatives or design new alternatives) or to search for new alternatives.

;igure 7.2
;upport of the Development Phase



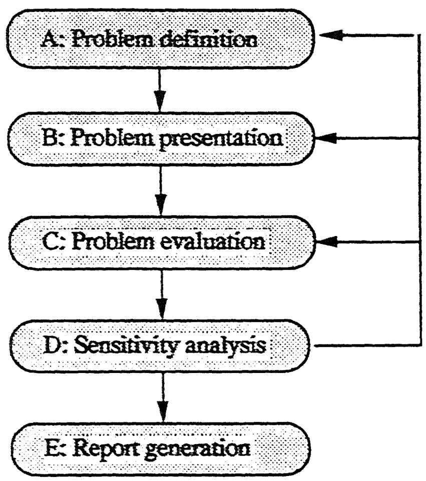

Cycling through the system supports elaboration of the problem: one idea .ctivates a whole set of ideas. It also supports selection: identifying the key ;sues of the problem. This may result in an adjustment of existing alterna- ives, the development of new alternatives, and the deletion of irrelevant al- ernatives. The purpose of this function is to obtain a more complete and .dequate set of alternatives.

The functions ascribed to a MODSS have resulted in the development of )EFINITE, an MODSS to support DEcisions with a FINITE set of alterna- ives in relation to a finite number of criteria.[1] The system can be used to upport a variety of environmental planning problems, ranging from siting he new high-speed train link from Brussels to Amsterdam to the selection of policy scheme to reduce carbon dioxide emissions. The system supports he whole decision process, from problem definition to report generation.

## 'HE DEFINITE PROGRAM

DEFINITE aims at users with sufficient general education but without pecific experience in evaluation methods or computer programs and with .me constraints. The five modules of the system are shown in Figure 7.3.

**Figure 7.3**
**DEFINITE Structure**




*Problem definition* results in an effects table representing the decision problem. *Problem presentation* results in various presentations of the effects table. The effects table can be presented as an appraisal table, a graph, a scatter diagram, or a cost-benefit sheet. *Problem evaluation* generates a complete or incomplete ranking of the alternatives, the best alternative, or a set of acceptable alternatives. The presence of multiple dimensions, sometimes even of different measurement scales, is handled through multicriteria analysis or cost-benefit analysis. The sensitivities of the results of problem evaluation to uncertainties in scores, weights, and prices, together with the sensitivity of the ranking to the evaluation method used, are analyzed in module D, *sensitivity analysis.* All results are combined into an evaluation report in module E, *report generation.*

Each module contains a variety of procedures to perform these functions. In the following section a selection of these procedures is described. A full description of the DEFINITE program can be found in Janssen and van Herwijnen (1992). The program can be described according to five topics:

1. *The completeness of the effects table.* An important difficulty in problem definition is to reach a complete effects table. Two procedures are included to generate a set of alternatives that is as complete as possible and one procedure to support the selection of the evaluation criteria.
2. *Possibility of low information level.* Effect scores are not always available as hard numbers. To be able to include all information, the program accepts low information scales such as ordinal, binary, and nominal scales.
3. *Creativity in problem formulation.* The user is stimulated and supported to create

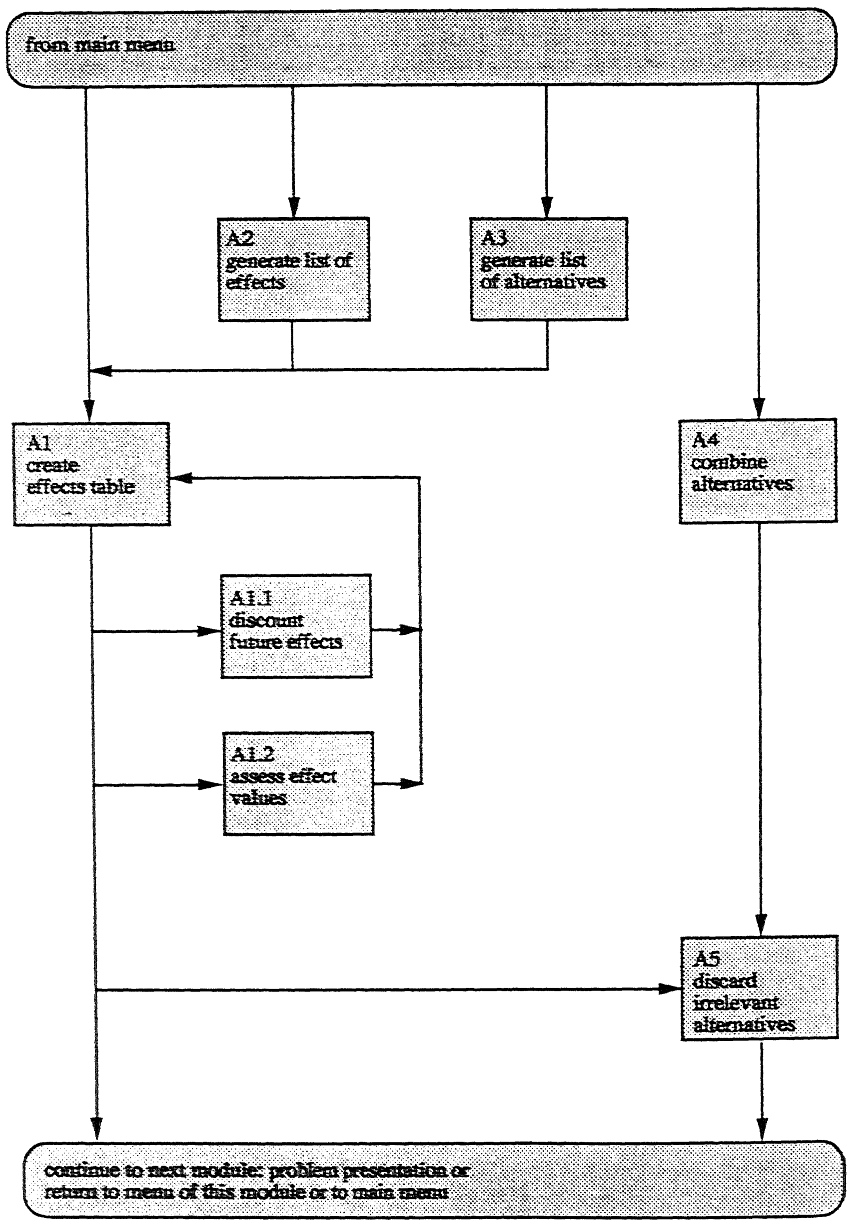
new alternatives or new combinations of alternatives. Since procedures are available to reduce the number of alternatives at a later stage, the user is not restrained from inventing infeasible alternatives.

4. *Presentation versus aggregation.* In problems with a small number of alternatives or criteria, an adequate presentation can be sufficient to evaluate the alternatives. In these cases, the alternatives are ranked according to the overall impression provided by the presentation. If an adequate presentation is available, there is no need to use a formal decision rule to aggregate the scores.
5. *Negotiations.* In module D, the sensitivity of all chosen values and methods can be examined. Certainty intervals can be calculated for weights and scores so that within such an interval, the ranking of alternatives is not sensitive to changes in scores or weights. This is useful in negotiations if there are different opinions on scores and priorities.

## PROBLEM DEFINITION

The purpose of module A, problem definition, is to obtain an effects table that represents the decision problem. All procedures of this module are shown in Figure 7.4.

**Figure 7.4**
**Procedures Model A: Problem Definition**



### Completeness

An important difficulty in problem definition is reaching a complete effects table. Completeness of the set of alternatives may be achieved by using procedure A3 in Figure 7.4. The user is requested to identify a number of aspects of the problem at hand and to specify, for each aspect, options for the solution of the problem. Furthermore, the user specifies which combinations of options are not feasible. The combination procedure now generates all possible alternatives.

*Example 1*

The seaside resort of Deil aan Zee is separated from the main urban area by the river Traach. The problem is how to provide a connection across this river. Table 7.1 shows three aspects to this problem and two or three possible solutions for each aspect.

**Table 7.1**
**Input to the Combination Procedure**

| aspects | solutions | | |
|---|---|---|---|
| Means of transport | Train | Car | |
| Type of connection | Ferry | Tunnel | Bridge |
| Capacity (persons/day) | 10,000 | 100,000 | |

The user subsequently specifies that the combination Train and Ferry and the combination of Ferry and a capacity of 100,000 persons/day are not feasible. The procedure generates nine alternatives as shown in Table 7.2.

**Table 7.2**
**Output of the Combination Procedure**

| Alt 1 | Alt 2 | Alt 3 | Alt 4 | Alt 5 | Alt 6 | Alt 7 | Alt 8 | Alt 9 |
|---|---|---|---|---|---|---|---|---|
| Train | Train | Train | Train | Car | Car | Car | Car | Car |
| Tunnel | Tunnel | Bridge | Bridge | Ferry | Tunnel | Tunnel | Bridge | Bridge |
| 10,000 | 100,000 | 10,000 | 100,000 | 10,000 | 10,000 | 100,000 | 10,000 | 100,000 |

A complete set of alternatives can also be achieved by aggregating all possible combinations of elements into alternatives. This is performed by procedure A4. The user specifies elements and combination rules. The procedure generates all combinations of elements that comply with these combination rules.

*Example 2*

To secure the water supply for the seaside resort of Deil aan Zee a minimum of 10,000 $m^3$/year needs to be extracted from groundwater stocks. Table 7.3 shows that four wells are available in the dune area nearby. These wells (the elements) have a capacity of 3,000, 5,000, 2,000, and 6,000 $m^3$/year.

**Table 7.3**
**Input to the Aggregation Procedure**

| | | Element 1 | Element 2 | Element 3 | Element 4 |
|---|---|---|---|---|---|
| Capacity | $m^3$/year | 3,000 | 5,000 | 2,000 | 6,000 |
| Land use | $m^2$ | 200 | 400 | 200 | 700 |
| Groundwater | cm | -5 | -10 | -4 | -15 |

Combination rule: each alternative must produce at least 10,000 $m^3$/year and no more than 12,000 $m^3$/year. This results in the following alternatives:

Alternative 1 = Element 1 + Element 2 + Element 3
Alternative 2 = Element 1 + Element 3 + Element 4
Alternative 3 = Element 2 + Element 4

The resulting effects table as shown in Table 7.4 is derived by summing for each alternative the scores of the elements (the columns of Table 7.3) included in the alternatives.

**Table 7.4**
**Output of the Aggregation Procedure**

| | | Alt. 1 | Alt. 2 | Alt. 3 |
|---|---|---|---|---|
| Capacity | $m^3$/year | 10,000 | 11,000 | 11,000 |
| Land use | $m^2$ | 800 | 1,100 | 1,100 |
| Groundwater | cm | -19 | -24 | -25 |

### Low Information Level

Effect scores are not always available as hard numbers. To be able to include all information DEFINITE accepts low information scales such as ordinal, binary, and nominal scales (see Table 7.5).

*Example 3*

Traffic congestion occurs on a road between Deil aan Zee and the nearby city of Nijverhoeck. Three alternatives are available to solve this problem: a four-lane highway, a new road combined with special bus lanes, or a new train connection. The expected effects of the three alternatives are listed in Table 7.5.

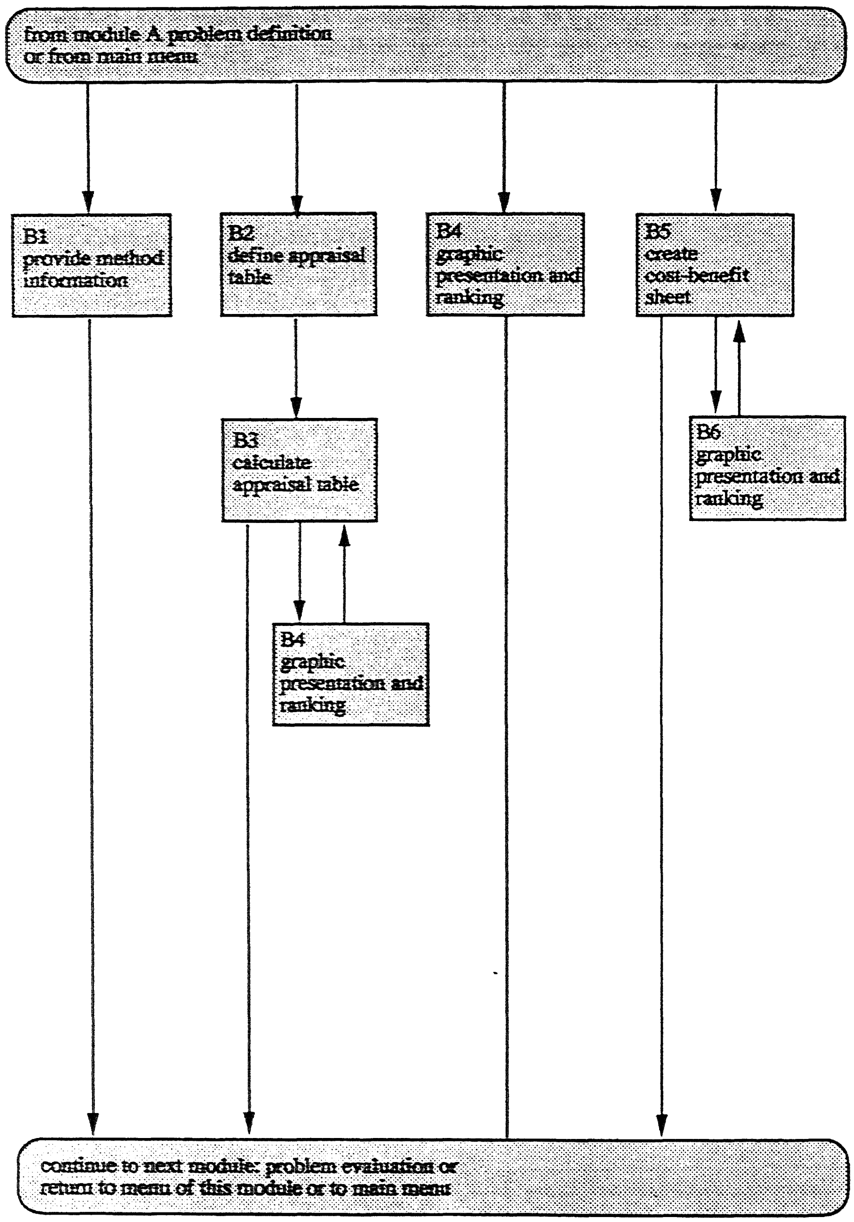
**Table 7.5**
**Improve Transportation to Nijverhoeck**

| criteria | units | Highway | Road/bus | Train |
|---|---|---|---|---|
| Costs | mln gld. | 200 | 250 | 400 |
| Travel time | ---/+++ | +++ | ++ | + |
| Capacity | mln/km/year | 20 | 30 | 40 |
| $NO_x$ emissions | ton/year | 1,000 | 750 | 100 |
| Landscape | ---/+++ | --- | --- | - |

## PROBLEM PRESENTATION

The purpose of module B is to present the effects table in a form that supports comparison of the alternatives without applying a formal decision rule. All procedures in module B are shown in Figure 7.5.

**Figure 7.5**
**Procedures Module B: Problem Presentation**



### Presentation versus Aggregation

Presentation can replace aggregation in problems with a small number of alternatives or criteria. In these cases, the overall impression provided by the presentation replaces the scores calculated by decision rules.

*Example 4*

A graphic presentation of Table 7.5 is shown in Figure 7.6. For each criterion, the highest bar indicates the best alternative. After the criteria are ordered, in descending priority, the alternatives can be ranked visually (Figure 7.7).[2]

**Figure 7.6**
**Graphic Presentation of an Effects Table**

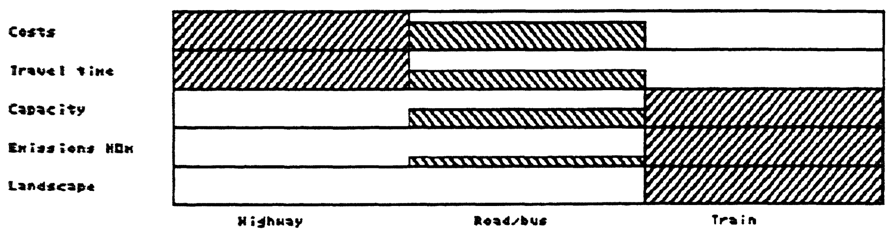
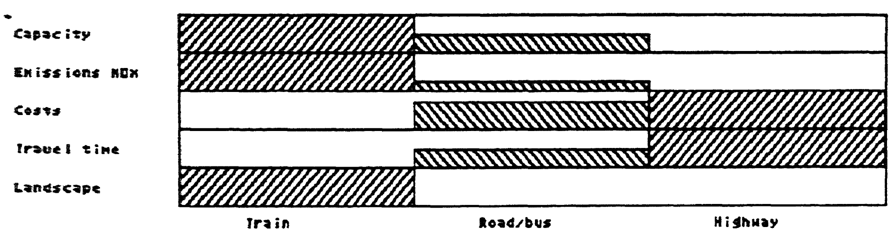



**Figure 7.7**
**Graphic Presentation of a Sorted Effects Table**



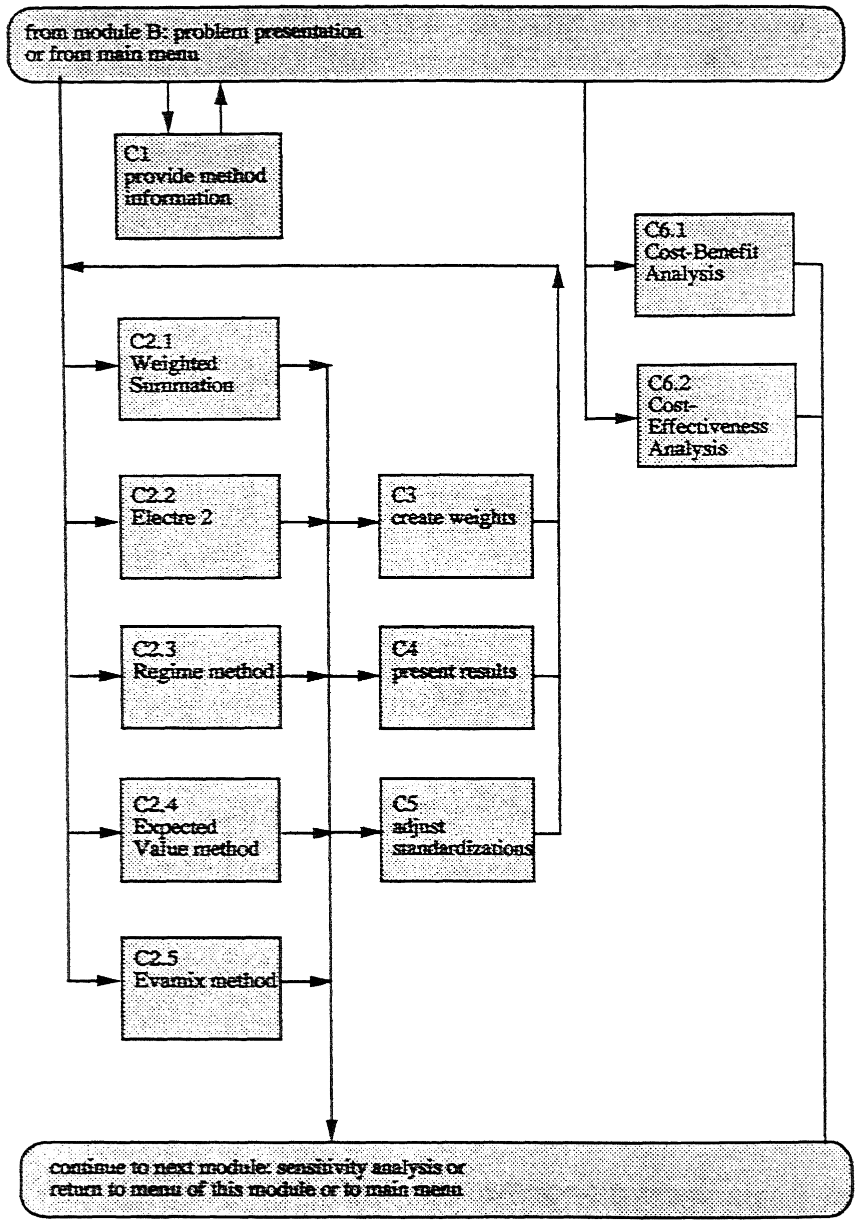

## PROBLEM EVALUATION

This module contains two main categories of procedures: monetary evaluation methods and multicriteria methods. All methods result in a ranking of the alternatives by aggregating the effects table according to the decision rules assumed. All procedures in module C are shown in Figure 7.8.

### Low Information Level

Multicriteria analysis requires information on priorities. A decision maker can usually express opinions on priorities only in a qualitative form. DEFINITE contains various procedures to transform this low-level information into quantitative weights as required by the various multicriteria methods.

**Figure 7.8**
**Procedures Module C: Problem Evaluation**



The expected value method, for example, asks the user to order the effects in descending priority order. Each weight is calculated as the expected value of all values conforming to the rank order of that weight. Another method, the analytical hierarchy process (AHP), requires much more information. In this method, the user is not only asked to compare each pair of criteria but also to express whether one criterion is more important, strongly more important, and so forth, than the other criterion. The weights are calculated as the eigenvalues of the resulting matrix of pairwise comparisons. Other methods for dealing with qualitative information or priorities are the extreme value and the random value method.

*Example 5*

To calculate the expected values of the weights the user has specified that capacity is as important as $NO_x$ emissions, $NO_x$ emissions are more important than costs, and so on. As described above, to calculate the eigenvalues information on all pairs of criteria is required. In this example capacity is equally important as $NO_x$ emissions, capacity is moderately more important than costs, capacity is strongly more important than travel time, and so on. The results of both methods are shown in Table 7.6.

**Table 7.6**
**Weights according to the Expected Value Method and the Eigenvalue**

| ranking | Expected Value | Eigenvalue |
|---|---|---|
| 1. Capacity | 0.357 | 0.379 |
| $NO_x$ emissions | 0.357 | 0.379 |
| 2. Costs | 0.157 | 0.140 |
| 3. Travel time | 0.065 | 0.051 |
| Landscape | 0.065 | 0.051 |

DEFINITE contains five multicriteria methods to transform the effects table in combination with the weights into a ranking of the alternatives:

- The weighted summation method derives the ranking from the weighted sum of standardized effect scores;
- The electre method is based on graphs derived from pairwise comparisons of all alternatives;

- The regime method is specially designed to handle qualitative or partly qualitative effects tables. The method is based on partitioning the set of values in accordance with the ordinal effects scores;
- The expected value method derives the ranking from the weighted sum of the expected value of the effect scores;
- The evamix method ranks the alternatives according to a combination of a dominance index calculated from the qualitative scores, and a dominance index calculated from the quantitative scores.

The results of the regime and expected value methods are presented in Tables 7.7 and 7.8.

**Table 7.7**
**Results of the Regime Method**

| WEIGHTS | RANKING | |
|---|---|---|
| rank | rank | score |
| 1. Capacity | 1. Train | 1.00 |
| $NO_x$ emissions | 2. Road/bus | 0.46 |
| 2. Costs | 3. Highway | 0.04 |
| 3. Travel time | | |
| Landscape | | |

**Table 7.8**
**Results of the Expected Value Method**

| WEIGHTS | | RANKING | |
|---|---|---|---|
| rank | score | rank | score |
| 1. Capacity | 0.357 | 1. Train | 0.82 |
| $NO_x$ emissions | 0.357 | 2. Road/bus | 0.50 |
| 2. Costs | 0.157 | 3. Highway | 0.27 |
| 3. Travel time | 0.065 | | |
| Landscape | 0.065 | | |

These tables show that both methods result in the same ranking of the three transportation alternatives. To apply the regime method only qualitative information on weights was required. To apply the expected value method this qualitative information was first transformed into quantitative weights.

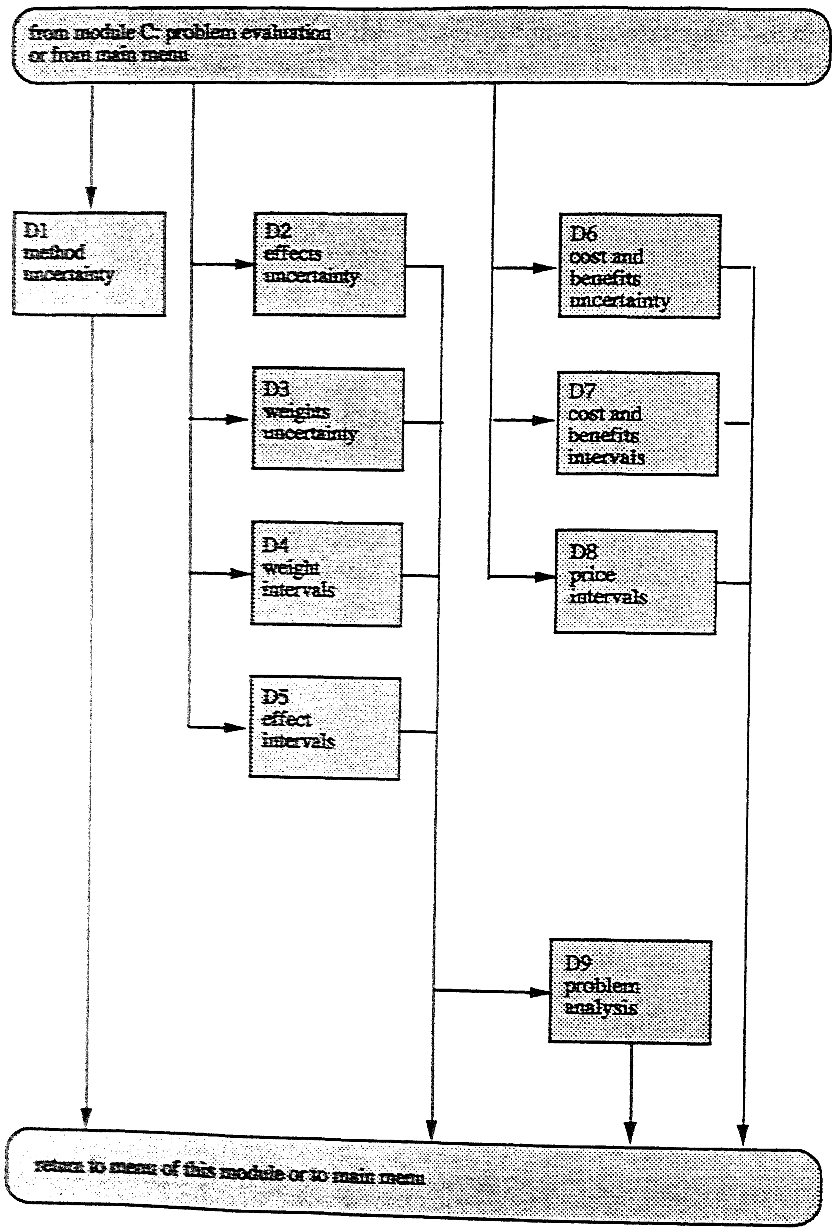
## SENSITIVITY ANALYSIS

The sensitivities of the rankings obtained in module C to changes in evaluation methods, effect scores, and weights are analyzed in module D (see Figure 7.9). The module contains procedures to:

- assess the sensitivity of the ranking to the evaluation method applied (method uncertainty);
- assess the influence of uncertainties in scores and weights on the ranking of the alternatives (effects and weights uncertainty); and
- determine the intervals within which the rank order of two alternatives is insensitive to changes in scores or weights (effect and weight intervals).

Special search procedures are developed for determining these intervals for all evaluation methods included in the system.

**Figure 7.9**
**Procedures Module D: Sensitivity Analysis**



**Negotiations**

Score, weight, and price intervals can be useful in negotiations when participants hold different views on certain scores or priorities.

*Example 6*

As shown in Table 7.7, the regime method ranks alternative train before road/bus and highway. In Figure 7.10, certainty intervals are calculated to test the stability of the highest-ranked alternative with respect to the expected capacity of the alternatives highway and road/bus. The difference between the start value and the reversal value is considerably smaller in the comparison between the alternatives train and road/bus (Figure 7.11) than in the comparison between alternatives train and highway.

**Figure 7.10**
**An Effect Interval for the Score of Capacity of Alternative Highway**

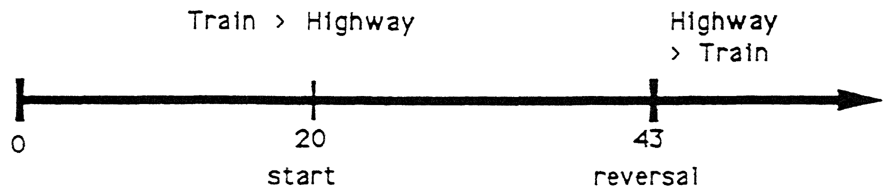
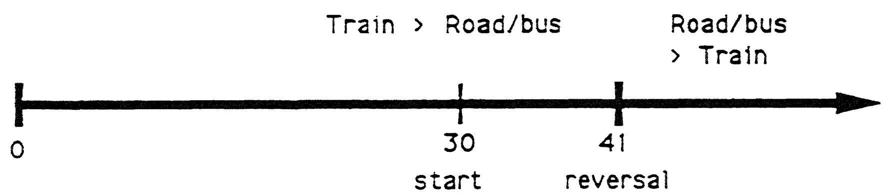


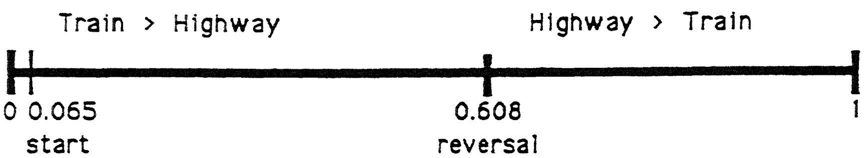

**Figure 7.11**
**An Effect Interval for the Score of Capacity of Alternative Road/Bus**




*Example 7*

The same can be done in procedure D4 where DEFINITE calculates certainty intervals for weights. The user specifies the weight to be tested and two alternatives for comparison. The result of this procedure is presented in Figure 7.12. This figure shows that the weight assigned to the criterion travel time needs to be increased considerably to change the ranking order of train and highway as calculated with the expected value method.

**Figure 7.12**
**A Weight Interval for Criterion Travel Time**




Only the relative weight of criterion travel time was changed in calculating the weight intervals in Figure 7.12; the ratios of all other weights were held constant. If all weights are allowed to change freely, it becomes clear how sensitive the ranking is to overall changes of the weights.

Table 7.9 shows the weight set with the smallest Euclidean distance from the original weight set that causes a rank reversal of alternatives train and highway. This table shows that the nearest weight combination that results in a rank reversal differs considerably from the original set of weights.

**Table 7.9**
**A Weight Combination with Rank Reversal: Expected Value Method**

| original ranking | | | reversed ranking (distance 0.316) | | |
|---|---|---|---|---|---|
| Capacity | 0.357 | 1. Train | Costs | 0.347 | 1. Road/bus |
| $NO_x$ emissions | 0.357 | 2. Road/bus | Capacity | 0.203 | 2. Highway |
| Costs | 0.157 | 3. Highway | $NO_x$ emissions | 0.192 | Train |
| Travel time | 0.065 | | Travel time | 0.177 | |
| Landscape | 0.065 | | Landscape | 0.081 | |

## CONCLUSIONS

The use of DEFINITE to support the decision process has clear advantages:

- It supports the decision making as a cyclical process.
- It enables the decision maker to incorporate all relevant information in the decision; it counteracts the unsatisfactory practice of limiting the information included to the number of issues that can be handled by a single individual.
- It stimulates learning by doing.
- It can focus debate in decision making by negotiation.

DEFINITE has a bias toward rational, normative decision making. With the exception of the graphic presentation, all results are produced using a formal decision rule. DEFINITE will not be popular with decision makers who seek other, perhaps more subjective decision procedures. In further development of MODSS, it is essential to put more emphasis on the behavioral aspects of the use of these systems (see also Yu 1990; Timmermans 1991; Vlek, Timmermans & Otten 1991).

## NOTES

1. The development of DEFINITE was commissioned by the policy analysis department of the Ministry of Finance, the Hague. The Dutch version of DEFINITE was developed in cooperation with this department. DEFINITE is available from Kluwer Academic Publishers, Dordrecht (Janssen & van Herwijnen 1992). The software of the DEFINITE system was written by M. van Herwijnen.
2. If prompted, DEFINITE performs the sorting of the columns automatically using the expected value method in combination with weighted summation.

## REFERENCES

Gorry, A., and M. S. Scott Morton. (1971). A framework for information systems. *Sloan Management Review, 13,* 55–70.

Janssen, R. (1992). *Multiobjective decision support for environmental management.* Dordrecht: Kluwer Academic Publishers.

Janssen, R., and M. van Herwijnen. (1992). *DEFINITE: A system to support decisions on a finite set of alternatives.* Dordrecht: Kluwer Academic Publishers.

Mintzberg, H., D. Raisinghani, and A. Théorêt. (1976). The structure of unstructured decision processes. *Administrative Science Quarterly, 21,* 246–275.

Timmermans, D. (1991). Decision aids for bounded rationalists: An evaluation study of computerized decision support in an individual and group setting. Ph.D. dissertation, University of Groningen.

Vlek, C., D. Timmermans, and W. Otten. (1993). The idea of decision support. In this book.

Yu, P. L. (1990). *Forming winning strategies: An integrated theory of habitual domains.* Berlin: Springer.

# Part Four

# Expert Systems Software

8

# Program Evaluation via Function-based Expert Systems

PAUL J. HOFFMAN

The term *expert systems software* sounds more esoteric and high-tech than it ought to be. In reality, the concept is simple. The objective is to create computer software that will enable users to emulate experts—that is, to have the computer make decisions about alternatives in the same way that knowledgeable experts would make those decisions.

Perhaps the most familiar example of expert systems software is an airline reservation system. Enter a point of departure, a date, and a destination from the keyboard, and a good airline reservation system will display the flights that have seating available, along with their routes and type of service. A less familiar example is a system for the evaluation of research proposals. Select a proposal from the software's data files; then select a committee from the software's expert system directory. The proposal is automatically evaluated with respect to the standards and objectives of the committee and is immediately displayed to the user, ranked in relation to the other proposals on each of a number of key factors.

Program evaluation is exactly analogous to proposal evaluation. The only difference is that the "committee" whose expertise is available in the computer's files is in fact composed of stakeholders with different frames of reference and different levels of responsibility for decision making.

The origin of such systems is clearly with an expert or group of experts. For airline reservations, the group of experts are available to the software developers to help make decisions about routes and to assist in the formulation of algorithms. One such algorithm is availability (what number of extra passengers do you book when the space on a flight is 100 percent sold, on the expectation that a given number of the passengers will be no-shows?). For program evaluation, the knowledge and experience of the stakeholders

(about the decision problem, not about computers) is the key to effective, precise, and well-documented decision making, and the algorithms needed have to do with modeling the personal, intuitive judgmental processes of the stakeholders, who in real life must make trade-offs between various outcomes and objectives.

Expert systems can be employed in a wide range of activities, and to considerable advantage: business decisions, policy studies, medicine, sentencing guidelines, personnel selection, and other fields of endeavor. Their main advantage is an obvious one: organizations will be able to utilize expertise in their decisions, even if the experts are physically unavailable at the time. If the expert systems have been properly engineered, such organizations will have use of a completely reliable tool for their decisions—a tool with internal logic that presumably has been subjected to rigid testing to ensure that automated decisions properly represent the decisions that would in fact have been made by the organization's experts, had they been available.

This chapter illustrates the manner in which expert systems can be so employed, explains how they operate, and illustrates their role in decision support. Discussion will be limited fairly exclusively to function-based expert systems (Hoffman 1985), as opposed to rule-based expert systems (Harmon 1985).

## RULE-BASED EXPERT SYSTEMS

Rule-based expert systems evaluate information by means of a set of rules that experts believe are important to the decision and that system developers build into the software of their system. These are, for the most part, Boolean expressions, that is, of the form:

If A and B and not (C or D) then X.

For example, consider the evaluation of candidates for a postdoctoral fellowship. The above rule might take the form:

> If the candidate scores above the 90th percentile on the Graduate Record Examination and the candidate has strong recommendations from the faculty and the candidate is not a biology or a social science major then
> Assign the candidate a B+ rating.

A single rule-based expert system typically is composed of a very large collection of rules; if the number exceeds 100 to 150, as it often does, the rules are structured so that the information required by certain rules is provided by the application of other rule sets to the information base. The mechanism that controls the evaluation of rule sets is often referred to as the *inference engine*. When a subset of information is entered by the user, the

computer-based processes set in motion include testing individual rules, drawing inferences from the available information, and identifying the need for new information. The range of complexity and diversity of rule-based expert system tools is considerable. The objective is to reach conclusions among alternatives, based on the information base, the knowledge base, including the rule set, and new information provided by the user.

There are a number of problems associated with Boolean rule-based systems, among them, *obfuscation, insufficiency, capitalization on chance, validity,* and *relativity.*

*Obfuscation* occurs as an inevitably natural by-product of the development of rule-based systems. It becomes apparent when users attempt to understand the logical process that underlies the decisions made by the system. Because of the sheer complexity of typical rule sets and the algorithms that control the order of their application, few, if any, users will develop a clear understanding of the basis of machine-made decisions.

*Insufficiency* refers to errors in the evaluation of alternatives that result from the use of machine-derived inferences in the absence of needed data. Given a degree of uncertainty in the quality of the inferences, the problem occurs because rules may assume the presence of certain information required by the rule, and the absence of the information can prevent the rule from being applied, unless the information is derived from other information sources, evaluated by other rules. The need for derived information may be trivial or extensive. The more extensive the need is, the more uncertainty is introduced into the evaluation. Thus, the accuracy of evaluations may be high or low, depending on the sufficiency of information available. The user will not likely know the seriousness of this effect.

*Capitalization on chance* occurs in two principal ways: when the inference engine begins processing rules in a search of relationships within the database and, in the course of development of the software, when the developer iteratively tests and corrects the program so as to minimize the frequency and seriousness of erroneous results. In both cases, the accuracy of results is inflated because degrees of freedom are "used up" in the course of fitting rule structures to the data. This problem is analogous to the well-known shrinkage problem (the overfitting problem) in regression analysis (McNemar 1949).

*Validity* refers to the accuracy of the decision model. When applied to expert systems, accuracy has two connotations: it may refer to the ability of the expert system to make correct decisions and to the fidelity of the expert system, that is, the extent to which the decisions made by the expert system are the same as the decisions that would have been made by a reliable expert or group of experts on whom the expert system is based. Users of rule-based expert systems should attempt to ensure that at least one of these two tests of validity has been met before trusting the results.

*Relativity* refers to the manner in which the expertise of a group or com-

mittee is distributed among the different components of the problem. Given that any alternative is evaluated on the basis of objective data, it is nevertheless the case that the same set of objective data can and probably should be evaluated differently by different experts. That is, experts will differ in the manner in which they wish to interpret objective data, perhaps believing that certain outcome variables should be given more weight than others. And some experts will be properly seen as more knowledgeable or more insightful than others for certain components of the decision problem but not for other components, as a result of which the viewpoints (and personal standards) of different experts should be given more weight in proportion to their expertise. Rule-based expert systems almost universally neglect this problem.

Herein lies an important principle, which applies as well to everyday decision making as to sophisticated, computer-based expert systems: the evaluation of alternatives is, and should be, relative to the standards and values of the expert. Two important requirements follow from the principle:

1. Expert systems should be constructed so as to permit the allocation of expertise among various components of the problem, according to the talents and responsibilities of the experts.
2. When utilized as decision support systems, expert systems should clarify for the user the exact manner in which expertise has been distributed among the various components of the problem.

## FUNCTION-BASED EXPERT SYSTEMS

Function-based expert systems use algebraic functions to emulate the intuitive mental processes of experts engaged in decision making. A simple example is an expert system for graduate admissions based on the applicant's undergraduate grade point average (GPA), Scholastic Aptitude Test (SAT) scores, and a measure of the quality of the undergraduate program (Dawes 1971). In this example, it was possible to express (with considerable validity) the decisions made by admissions committees as simple weighted functions of the three variables:

$$J = a_1X + a_2Y + a_3Z + a_0$$

where

$J$ = the committee judgment of each applicant,

$X$, $Y$, and $Z$ = the attributes GPA, SAT, and quality of the undergraduate program, and

$a_0$, $a_1$, $a_2$, and $a_3$ = parameter estimates of a linear model that optimizes the least-squared deviations of the model's predictions from the committee's judgments.

In the study cited, Dawes found that the model of the committee was not only more reliable than the committee itself but also that the predictions of graduate success based on the model were more valid than were the predictions made by the committee. The study is a classic illustration of the bootstrapping effect (Hogarth 1980; Ebert & Kruse 1978), demonstrating the superiority of simple models over the more fallible judgments of individuals.

### Hierarchical Structure

The graduate admissions example is atypical of personnel selection decisions in industry and government, wherein each applicant must be evaluated on a score or more variables. Indeed, the example is atypical of program evaluations and policy evaluations for the same reason. To do justice to evaluation, one must examine a multitude of information from a variety of sources, and not all of the information is initially in objective form. Can simple regression analysis be used for these other classes of problems?

The answer is a qualified "no." In Dawes's study, data were available from a moderately large ($N = 77$ to 93) sample of students. In addition, a very small number of variables was considered, and a surprisingly simple linear model was deemed a priori to be sufficient. Therefore, the residual degrees of freedom were large enough to permit reasonably accurate estimation of the parameters of the model. In a typical program evaluation study, however, just the opposite conditions apply. Typically, the sample size (for example, of competing programs or interventions being evaluated) is small, the number of dependent variables is typically large, and a linear model might very well not apply. Therefore, regression analyses under these conditions are bound to yield poor or misleading parameter estimates.

To deal with these problems, function-based expert systems give careful attention to the hierarchical structure of dependent variables. These variables, which are referred to as *attributes,* are grouped into meaningful clusters, and the clusters are assigned names. Each cluster is referred to as a *concept,* to denote the fact that it exists at a higher level of abstraction (Hayakawa 1947) than its defining attributes.

To illustrate the distinction between attributes and concepts, consider the task of a National Institutes of Health (NIH) study section on cardiovascular disease and stress, evaluating competing research proposals.[1] Were the committee to jot down the factors that should be considered in evaluating the proposals, an unstructured list might be like the one shown in Figure 8.1.

In a function-based expert system, the organization's experts and the developer work to cluster the attributes into an organized hierarchy that is uniquely meaningful for the evaluation problem. For example, items 1, 7, 9, 11, and 12 form a related set of attributes in the sense that each is a compo-

**Figure 8.1**
**Attributes for the Evaluation of Proposals**

1. Knowledge of the literature
2. Competence of investigators
3. Library resources available
4. Seriousness of Public Health problem to be investigated.
5. First year costs
6. Long-term costs
7. Analytic methodology
8. No. of lives improved
9. Salience of the problem
10. Accessibility of a clinic
11. Appropriateness of hypotheses
12. Design Methodology
13. Probability of project success
14. No. of publications of research team
15. Quality of publications of team
16. Likelihood that project will engender public support
17. Laboratory space available
18. Computer resources available
19. Support-staff adequacy

*Note:* The list of attributes is undifferentiated. It lacks organization and coherence.

nent of the scientific merit of any program or proposal. The label "scientific merit" was chosen by the committee, which by then understood clearly that it is defined by its subordinate attributes. If other attributes are considered essential to the meaning of the concept, they are added at this time.

Further study of the attributes of Figure 8.1 reveals additional insights. Items 5 and 6 have to do with economics. Attributes 4, 8, 13, and 16 have to do with the public health impact of the study. An example of a completely structured hierarchy for the research proposal problem is shown in Figure 8.2.

It is seldom difficult to work through the details of constructing problem hierarchies. In Figure 8.2, we have been able to group nineteen original dependent variables, or ratings, into five concepts: scientific merit, team competence, facilities, economics, and public health impact.

While the first problem for function-based expert systems development is to conceptualize the problem dimensions hierarchically, the second problem is to generate algebraic functions for each of the concepts—functions that map attribute values into measures of the concepts in a manner that emulates the intuitive way in which experts would actually evaluate the concept, given the attribute set. This problem is solved by modeling the intuitive judgmental processes of experts.

## EXAMPLE-BASED EXPERT SYSTEM DEVELOPMENT

The solution to this problem has its roots in paramorphic representation (Hoffman 1960), modified according to a particular set of specifications for the generation of hypothetical examples, to which experts respond with their

**Figure 8.2**
**Same Attributes, Structured Hierarchically**

OVERALL MERIT OF PROPOSAL

1 SCIENTIFIC MERIT
Knowledge of literature
Salience of problem addressed
Appropriateness of hypotheses
Design methodology
Analytic methodololgy

2 TEAM COMPETENCE
Training and credentials of the principal investigators
Publications (quantity) of the principal investigators
Publications (quality) of the principal investigators
Support staff adequacy

3 FACILITIES
Library space available
Computing resources available
Laboratory space availability
Accessibility/adequacy of clinic

4 ECONOMICS
Short-term costs
Long-term costs

5 PUBLIC HEALTH IMPACT
Probability of project success
Seriousness of Public Health problem
Number of lives improved
Impact on public support

*Note:* They are essentially those shown in Figure 8.1, but they are now grouped hierarchically into more meaningful concepts.

best judgments. The process is not unlike the well-known policy-capturing methodology described extensively by others (Slovic & Lichtenstein 1971, Hammond, McClelland & Mumpower 1980), except that the new features incorporated into EXPERT87 software overcome certain heretofore troublesome aspects of policy capturing. The new methodology abandons the traditional emphasis on empirical regression analysis in favor of hierarchically ordered design matrices for the generation of examples. A simple prototype of the application of these matrices can be found in Hoffman, Slovic, and Rorer (1968).

The EXPERT87 approach incorporates the following new features:

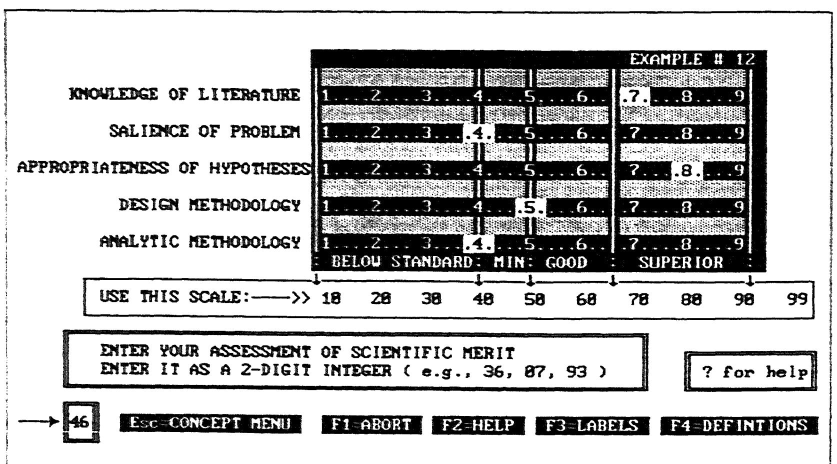
1. The attribute values used in the examples displayed to the experts are automatically created as optimally efficient, orthogonal, integer-valued sets.
2. The models that are to become components of the expert systems may be either linear or nonlinear.
3. The hierarchical structuring of attributes is such as to minimize the cognitive limitations in human information processing capacity (Miller 1956).
4. The parameters of the models are unambiguous estimates of the independent effects of the attributes and their nonlinear components.
5. Absolute scaling is incorporated, enabling evaluations of alternatives to be interpreted in terms of the standards of the experts.
6. The modeling process is consistent with the hierarchical structure of attributes and concepts.

The end result of the expert system development phase is a set of expert systems for each concept of the evaluation problem—expert systems that may be used to evaluate any alternative with respect to its corresponding concept, rank all alternatives on any concept of interest, and evaluate any selected alternative in an absolute sense.

Figure 8.3 is a computer-generated display that illustrates an important phase of function-based expert system development. The display is one of twenty-five examples presented to a stakeholder or committee member for judgment. The attributes displayed are those embodied in the first concept of the hierarchy, scientific merit. The expert interacts with the computer-generated examples at a terminal, entering a judgment on a 100-point scale in response to each example. In this instance, the expert has assigned a rating of 46 to the profile (shown in the lower left corner of the figure). This number indicates the expert's judgment of the scientific merit of a proposal, given the attribute values shown.

The precise number of examples displayed is under control of the program. The number varies from concept to concept, because different concepts are defined by different numbers of attributes, requiring the estimation of different numbers of parameters. An algorithm within the program defines the attribute values for each example set, as well as the

**Figure 8.3**
**A Sample Profile**




*Note:* Experts (committee members or stakeholders) enter judgments of the concept represented by the configuration of attribute scores. These hypothetical examples and the responses of experts comprise the data for completely automatic development of expert systems.

number of examples required, so as to optimize accuracy of parameter estimation while minimizing the total number of examples required.

Responses of experts to example sets provide the data required to generate the parameters of expert systems. This computational process is initiated immediately following the entry of the last judgment in a given example set, whereupon information about the expert's intuitive judgmental processes is immediately displayed on-screen.

An illustration of the parameters of an expert system is depicted in Figure 8.4. An expert, Albert, has interacted with a set of examples, on each of which are displayed committee ratings of the attribute values of a hypothetical proposal. Figure 8.2 depicts the attributes of one of the concepts of Albert's expert system. Also shown are some of the parameter estimates of the model. These are listed as component weights, weights that can map the set of attribute values into a measure of the concept, in this case, team competence. The mapping emulates the way in which Albert would intuitively respond to an actual proposal. That is, when the parameters of Albert's expert system are applied to the attribute values of an actual proposal, the resulting polynomial expression reflects Albert's personal standards and orientation with respect to the relative importance of the attributes. The component weights shown in the figure indicate that Albert gives significantly large weight to the investigators' credentials and their publication quality. He gives little weight to support staff adequacy.

In the figure, note the significant nonlinear (concave) effect corresponding to publication quantity. For Albert, this means that numbers of publications of a research team signifies greater team competence and that the

**Figure 8.4**
**Some Parameters of an Expert System**

```
SELECTED CONCEPT = TEAM COMPETENCE
CANDIDATE CLASS = PROPOSAL, NIH/NCI
EXPERT: (A) ALBERT1
PROPOSAL.WTS 10-26-1986 09:59:22
FIDELITY = 97.1
```

RELATIVE WEIGHTS ANALYSIS

| ATTRIBUTE | COMPONENT WEIGHTS LINEAR | NON-LIN | TOTAL | SHAPE |
|---|---|---|---|---|
| PI TRAINING & CREDENTIALS | 31.57% | 1.86% | 33.43% | POS.LINEAR |
| PI PUBLICATION QUANTITY | 10.80% | 11.15% | 21.95% | POS.CONCAVE |
| PI PUBLICATION QUALITY | 29.91% | 3.72% | 33.63% | POS.LINEAR |
| SUPPORT STAFF ADEQUACY | 9.14% | -1.86% | 11.00% | POS.LINEAR |
| TOTAL | 81.42% | 18.58% | 100.00% | |
| VARIANCE EXPLAINED | 88.21% | 6.11% | 94.32% | |

*Note:* The entries represent the relative importance of each attribute, as derived by EXPERT87. The relative strength of linear and non-linear effects is shown, as is the total contribution of each attribute to the evaluation of the concept. The fidelity index appears at the top of the figure.

incremental effect diminishes as the number of publications becomes large. Albert wants investigators to have at least a few quality publications to their credit, but beyond this, other factors come into play. Expert systems for the remaining concepts are derived in similar fashion, and their meaning can be similarly explicated.

A third problem for the expert system development tool is that of generating an algebraic function for mapping the derived concept scores into overall measures of the alternatives, thereby enabling the evaluation of alternatives with respect to their overall efficacy. This phase of development requires a slightly different kind of policy-capturing task, one whose hypothetical example sets depict alternatives with associated scores on each of the concepts rather than depicting concepts with associated scores on their attributes. The expert system that results from this process becomes a tool for evaluation of the overall efficacy of the alternatives, a process that, in the EXPERT87 environment, is carried out automatically.

## FEEDBACK OF EXPERTISE

Upon completion of these phases of expert system development, the user's files contain a set of expert systems for each expert. This can be portrayed as a two-way table, where rows represent experts, columns represent concepts, and each individual cell represents an expert system that maps a subset of attributes into a measure of the concept in a manner emulating the expert. In the EXPERT87 environment, such a table is referred to as an expert system directory. It would appear, on-screen, as in Figure 8.5.

If an expert has completed the judgments of an example set, an asterisk is displayed in the corresponding cell of Figure 8.5. If the user has decided to utilize a particular expert for evaluation of a selected concept, the letter *P* (patched) is shown in the cell. The configuration of patched expert systems represents the manner in which the user has decided to allocate the expertise of the stakeholders to the concepts of the evaluation problem.

Should the user elect to patch more than one expert to a given concept, so as to allow their collective expertise to be emulated, this can also be accomplished. What rationale can be used for aggregating expertise over stakeholders, or for choosing to accept or to reject the expertise of individual stakeholders? This question is discussed in the following paragraphs.

Within the operation environment of the software, the user is able to access any cell of the expert system directory and by doing so retrieve information about the expert system to which it refers. The data shown in Figure 8.4 represent one of the ways in which the information can be displayed to the user. It represents Albert's expert system when Albert deals with the concept "Team Competence." It tells us how important each attribute is to Albert, and it tells us the shape of the functions (positive, negative, concave, convex, or linear), helping us to understand more clearly how Albert uses attri-

**Figure 8.5**
**An Expert Systems Directory**

***** EXPERT DIRECTORY AND STATUS *****
---->> * = `COMPLETED' P = `PATCHED FOR SCORING'

| NAME | CODE | CREATED | CONCEPTS A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|---|
| ALBERT LISTER | ALBERT1 | 10-26-1986 | P | | * | | | * |
| EVELYN ENDIVE | EVELYN2 | 10-26-1986 | * | | * | * | | |
| CHARLES LEWIS | CHARLE3 | 11-14-1986 | | * | | * | P | |
| ENRICO CALIFANO | ENRICO4 | 11-21-1986 | | * | | * | | * |
| LAURA CHAU | LAURA#5 | 11-21-1986 | * | * | | * | * | |
| META-EXPERT | META--6 | 11-21-1986 | * | P | P | P | * | P |
| META-EXPERT | META--7 | 04-16-1991 | * | * | * | * | * | * |

Concept Directory: A = Overall Merit
B = Scientific Merit
C = Team Competence
D = Facilities Available
E = Economic (Cost) Factors
F = Public Health Impact

*Note:* Asterisks indicate the existence of expert systems for the corresponding expert and concept. The letter *P* indicates that the expert system has been patched, so as to be used in the evaluation of alternatives.

bute information when making judgments about proposals. Having this kind of information available is essential to users deciding how much weight to give to Albert's expert system, or indeed, whether to include Albert at all.

Ideally this information should be available for each concept of the hierarchy. Figure 8.6 displays indexes of relative importance for Charles Lewis for the concept "Scientific Merit." Figure 8.6b is a graphic display of the weights shown in Figure 8.6a.

Although this kind of information might well be considered when deciding how much weight to give to an expert's evaluation of a concept, experts will often vigorously defend the importance they attach to attributes, and it is often better either to compromise these differences algebraically or to bring disparate experts together, asking them to resolve the differences.

## ALLOCATION AND INTEGRATION OF EXPERTISE: THE PROPERTIES OF EXPERTS

Stylistic tendencies (Ramanaiah & Goldberg 1977) inherent in an individual's judgments provide a more cogent source of information that is extremely useful in deciding how much weight to give to an expert and whether to patch a given expert to a concept. I refer here to the response styles and biases of experts, some of which have been described in the literature as common errors (Smith 1983) and to measures of the "worth" of the expert

**Figure 8.6**
**Display of the Relative Weights of Attributes**

Figure 6a.

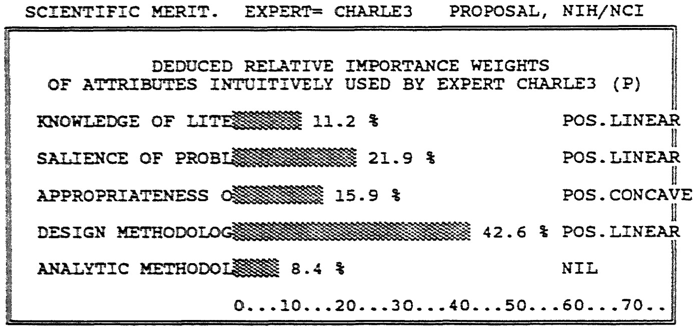
SELECTED CONCEPT = SCIENTIFIC MERIT
CANDIDATE CLASS = PROPOSAL, PROPOSAL, NIH/NCI
EXPERT: (C) CHARLE3
PROPOSAL.WTS 01-01-1992 09:59:01
FIDELITY = 95.20

RELATIVE WEIGHTS ANALYSIS

| | COMPONENT WEIGHTS | | | |
|---|---|---|---|---|
| ATTRIBUTE | LINEAR | NON-LIN | TOTAL | SHAPE |
| KNOWLEDGE OF LITERATURE | 9.37% | 1.83% | 11.20% | POS.LINEAR |
| SALIENCE OF PROBLEM | 20.37% | -1.54% | 21.92% | POS.LINEAR |
| APPROPRIATENESS OF HYPOTHESES | 9.13% | 6.74% | 15.87% | POS.CONCAVE |
| DESIGN METHODOLOGY | 38.68% | -3.94% | 42.62% | POS.LINEAR |
| ANALYTIC METHODOLOGY | 3.36% | -5.04% | 8.40% | NIL |
| TOTAL | 80.91% | 19.09% | 100.00% | |
| VARIANCE EXPLAINED | 86.93% | 3.82% | 90.75% | |

Figure 6b.

SCIENTIFIC MERIT. EXPERT= CHARLE3 PROPOSAL, NIH/NCI




VARIANCE EXPLAINED 86.93% 3.82% 90.75%

*Note:* The figure contrasts two formats for representation of the same data: tabular display (top panel) and graphics display (bottom panel). Both give insight into the relative weights of attributes intuitively used by an expert in the evaluation of "Scientific Merit." The entries reflect some of the parameters estimated via a function-based expert system approach.

system that is intended to reflect their judgments. Four such measures are considered here:

1. *Fidelity.* The goodness of fit of the model to the expert.
2. *Standards.* The extent to which the expert is "tough" versus "forgiving" when evaluating alternatives.
3. *Discriminability.* The extent to which the expert differentiates among alternatives, as opposed to using only a limited part of the scale.

4. *Typicality.* The extent to which the expert's viewpoint (or judgment style) is typi- cal of the viewpoints of other experts or stakeholders.

Decision support software can be designed to display these kinds of mea- sures to the user and to implement algorithms for aggregating expertise across experts in a manner that is responsive to the kinds of response styles and biases we have discussed. Function-based expert systems have this capa- bility.

Figure 8.7 displays tabular output of these indexes. With respect to the overall merit of proposals (the first block of data in the table), it is seen that (1) Evelyn is least typical, (2) all three expert systems have high fidelity, (3) Albert and Laura have lenient standards, whereas Evelyn has higher ex- pectations, and (4) discriminability is high for all three experts.

The column to the right indicates the weight assigned by the software to the expert, for purposes of creating a single model to emulate the entire group of stakeholders. Because the user has [illegible] Albert to concept A, "Overall Merit," neither Evelyn's nor Laura's expertise is considered in eval- uating this concept. (Laura is also shown as having been excluded from the

**Figure 8.7**
**Indexes of an Expert's Performance**

TABLES OF MEASURES OF EXPERTISE

| EXPERT | TYPICALITY | FIDELITY | STANDARDS | DISCRIM | WEIGHT |
|---|---|---|---|---|---|
| | CONCEPT A | | OVERALL MERIT OF PROPOSAL | | |
| ALBERT1 | 73.000 | 96.900 | 28.000 | [illegible] | [illegible] |
| EVELYN2 | 59.000 | 98.000 | [illegible] | [illegible] | [illegible] |
| LAURA#5 | 85.000 | 98.800 | [illegible] | [illegible] | [illegible] |
| | CONCEPT B | | SCIENTIFIC MERIT | | |
| CHARLE3 | 79.000 | 98.200 | [illegible] | [illegible] | [illegible] |
| LAURA#5 | 79.000 | 98.800 | [illegible] | [illegible] | [illegible] |
| | CONCEPT C | | TEAM COMPETENCE | | |
| ALBERT1 | 81.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| EVELYN2 | 81.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| | CONCEPT D | | FACILITIES | | |
| EVELYN2 | 69.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| CHARLE3 | 90.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| ENRICO4 | 82.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| LAURA#5 | 88.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| | CONCEPT E | | COST FACTORS | | |
| CHARLE3 | 74.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| LAURA#5 | 74.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| | CONCEPT F | | PUBLIC HEALTH IMPACT | | |
| ALBERT1 | 86.000 | [illegible] | [illegible] | [illegible] | [illegible] |
| EVELYN2 | 86.000 | [illegible] | [illegible] | [illegible] | [illegible] |

*Note:* These indexes are used to gauge the [illegible] component of the evaluation process.

model that evaluates concept D.) When more than one expert is to be included, an algorithm within the software implements a methodology capable of aggregating the expert systems of up to twenty-five experts on the basis of the four factors shown. The algorithm generates parameter estimates for a single comprehensive model and computes the relative weight given to each expert included. This is done separately by concept. The weightings of experts are displayed in the right-hand column of Figure 8.7.

That this kind of information is critical to decisions involving the weighting of experts should be self-evident. First and most obvious is the fact that unless the model of a given expert's judgments is accurate, there is not much rationale for including the expert at all. Low fidelity scores may be indicative of a poor choice of models, but in practice they are more indicative of an expert who is uncertain or inconsistent in the use of information about the concept. Second, experts who are quite capable of ranking alternatives may not have a reasonable basis for setting organizational expectations in an absolute sense. Therefore, experts whose biases are such as to cause their judgments to reflect very low standards or expectations should be candidates for exclusion in organizations attempting to upgrade their standards. The converse is also true.

Third, experts who experience difficulty in discriminating among alternatives may not be as effective as experts who discriminate well. Therefore, the discriminability scale provides a useful indicator for the differential weighting of an expert. Finally, experts whose weighting of attributes is extremely atypical of the majority of experts should be given a second look. It is possible that the atypical expert knows something of which other experts are only dimly aware; in this case, a group discussion among experts concerning the parameters of their models can be enlightening. But it is more likely that the isolated expert is "off the wall," in which case it would be unwise to give the identified expert system much weight.

Function-based expert systems can deal with the fact that different experts or stakeholders will have different kinds of expertise and perhaps differing responsibilities with respect to the decisions being made in an evaluation study or in an organization or agency being evaluated. The foregoing discussion suggests that the problem of allocating and differentially weighting expertise can be managed within an operating expert system environment.

## SENSITIVITY

Sensitivity refers to change in the value of an expression that is associated with change in the value of one of its variables. Mathematically, sensitivity can be gauged by the value of the partial derivative, given a set of values (in this case attribute values) of the variables. Users of function-based expert systems can be guided to a clearer understanding of the orientations of their experts by observing the effects of these changes in a dynamic graphic environment.

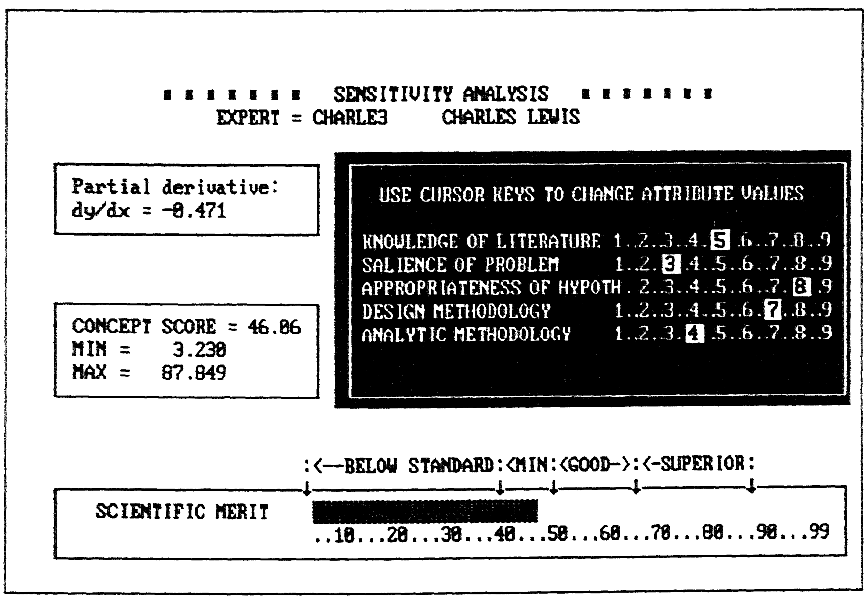
An example of a sensitivity screen is shown in Figure 8.8. When the screen appears, users can adjust the values of the attributes, moving them into any pattern they wish. As they do so, they will see, on-screen, the effects of these changes on the concept being evaluated. It is akin to a what-if game. The question is of the form: If one changes the rating of, say, knowledge of literature from a 7 to an 8, how much of a difference would that make to Charles Lewis's evaluation of "Scientific Merit"?

This kind of information might be of considerable use to users of expert systems as they attempt to decide how much weight to give to Charles Lewis's expertise in evaluating the scientific merit of the proposals. It would be equally useful to an administrator attempting to decide whether to fund borderline proposals, given uncertainty in the information base.

## FLEXIBILITY

Every evaluation directly or indirectly incorporates the personal utilities of responsible people within the organization. This being the case, it follows that when organizations change their priorities or when people change their viewpoints, the decision support systems of the organization should be able to adjust appropriately, so as to reflect these changes.

**Figure 8.8**
**A Sensitivity Screen**




*Note:* As users move a cursor to adjust the values of the attributes, they observe the resulting change in the concept score.

For these reasons, the allocation and redistribution of expertise within an operating expert system become significant factors in its usability and instrumental factors in decision support. The user may wish to add experts to an existing panel, delete others, or utilize an expert for evaluation of a different concept. It is important to have the flexibility to do this with a few keystrokes rather than having to redo an entire system development process. Alternatively, an expert may develop new insights about a decision problem and wish to substitute a new model in place of his or her original one. It should be a simple matter for the software to effectuate the desired changes and to be able to reevaluate alternatives, based on a revised model.

In the EXPERT87 environment, these changes are easily accomplished. The user can add or delete experts or change their degree of influence over the process with a few keystrokes. The properties of their expert systems can be reviewed on-screen, where decisions can be made about their inclusion or exclusion. And there are algorithms that assist the user in optimizing the allocation of experts to the various concepts of the decision task. Following these processes, the system generates and displays a table that indicates the precise manner in which expertise has been allocated by the system. One such table is shown in Figure 8.9.

Figure 8.9 represents a culmination of the process of creating an expert system adapted to the user's specific requirements. Upon completion of these steps, the user is ready to utilize the expert systems that have been created, for the purpose of evaluating alternatives. In this respect, one would wish to have available an expert system development tool that can also serve as a decision support system for the evaluation of alternatives and perhaps for guidance in making tough decisions.

**Figure 8.9**
**Allocation of Expertise among a Committee**

TABLE OF META-EXPERTISE
META-EXPERT = META--6
Entries are RWF's (relative weighting factors) for each Expert

| EXPERT | A OVERALL MERIT | B SCIENTIF MERIT | C TEAM COMPETNCE | D FACIL. AVAIL. | E ECONOMIC FACTORS | F PUBLIC HLTH IMPACT |
|---|---|---|---|---|---|---|
| ALBERT1 | 1.00 | | 0.58 | | | 1.00 |
| EVELYN2 | 0.00 | | | 0.55 | | 0.00 |
| CHARLE3 | | 0.68 | 0.42 | 0.08 | 1.00 | |
| ENRICO4 | | | | 0.38 | | |
| LAURA#5 | 0.00 | 0.32 | | 0.00 | 0.00 | |
| TOTAL | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

*Note:* The summary table indicates the contribution of each expert to the evaluation of proposals. The entries are calculated from the four indexes: fidelity, bias, discriminability and typicality, taking into account the user's decision to include or exclude particular experts in the evaluation of particular concepts.

## EVALUATION OF ALTERNATIVES: DECISION SUPPORT

In function-based expert systems, the database for decisions is a matrix of attribute values. The rows of this matrix represent alternatives (programs, candidates, proposals, interventions, etc.), and the columns represent attributes. The columns are grouped, so that sets of attributes that define concepts are clustered together. The process of evaluation is that of mapping the attribute values into objective measures of concepts and mapping concepts into an objective overall evaluation of each alternative. The expert systems created by the software serve as the transformation functions for this mapping.

It is of fundamental importance to realize that there is no single, unique formula for aggregating attribute values into measures of overall efficacy of alternatives. Evaluations are necessarily relative to the point of view of the stakeholders. This is as true in everyday life as it is in expert systems software. Therefore, decision support systems will be effective to the extent that they permit easy substitution of stakeholders and/or differential weighting of the points of view of stakeholders. One way of providing this mechanism was discussed in the previous section.

Once the desired expert system is in place, the user may display evaluations in a variety of formats. In the EXPERT87 environment, these options are depicted in the menu screen shown in Figure 8.10. Selection of option C from this menu produces a graph, on-screen, of the sort shown in Figure 8.11a. Here, the seven proposals before the committee are ranked and evaluated with respect to the concept "Team Competence." The lipoprotein proposal receives the highest rating, and the remote EKG monitoring proposal

**Figure 8.10**
**A Menu Screen for the Evaluation of Alternatives**

```
 Conceptual Dimensions                 Other functions / options
   of  MERIT OF PROPOSAL
 ------------------------------       ---------------------------------
 A. MERIT OF PROPOSAL                 U. PROFILE.  Evaluation of a
 B. SCIENTIFIC MERIT                       specific alternative.
 C. TEAM COMPETENCE                   V. DISPLAY current Expert System.
 D. FACILITIES                        W. PRINT Evaluations of alternatives
 E. ECONOMY OF COST                   X. EVALUATION of an imported set
 F. PUBLIC HEALTH IMPACT                   of alternative data.
                                      Y. PRINT Ranked alternatives from
                                           an imported set.
                                      Z. RETURN to Main Menu

              Enter an option:

 F1 = Esc               ENTER `#' TO CHANGE ATTRIBUTES
```

*Note:* The user may comparatively evaluate alternatives with respect to any selected concept. Alternatively, the user may select an alternative and review its evaluations on all concepts, as well as the overall evaluation.

**Figure 8.11**
**Evaluation of Two Concepts of Competing Proposals**

Figure 11a.

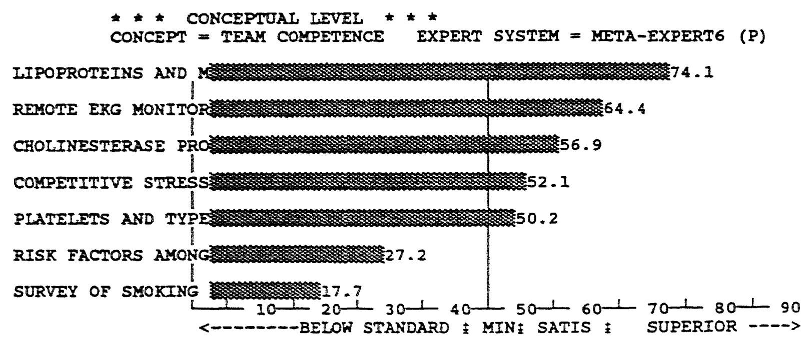
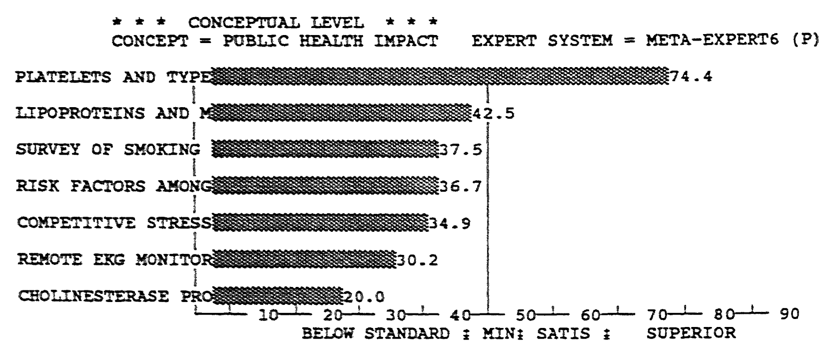



Figure. 11b.




*Note:* The concepts team competence (top panel) and public health impact (bottom panel) are shown. Alternatives are automatically ranked by the program with respect to each concept. The vertical line indicates a score below which proposals fail to exceed the minimal standards of the committee. This cutting score is based on an algorithm that automatically captures and reflects each expert's subjective standards.

also qualifies for a superior rating. Two of the proposals fall below the minimum level.

Selection of option F displays the same proposals, this time ranked with respect to "Public Health Impact" (Figure 8.11b). One can see by this example that the proposal named "Platelets and Type A" is ranked highest with respect to its potential public health impact, while all six of the remaining proposals are less than minimally acceptable. Since it was Evelyn's expert system that was chosen for evaluation of public health impact, it might be useful for the committee to review both the characteristics of Evelyn (fidelity, standards, etc.) and the attribute ratings of the proposals, to achieve a better understanding of why the platelets and type A proposal received such a high rating on this concept, relative to the others.

Selection of option A causes all proposals to be ranked and displayed in terms of overall merit of proposal (Figure 8.12a). In the example, three proposals fall in the superior range, with the lipoprotein and the type A proposals being clearly superior. The survey of smoking fails to reach a minimal level of acceptability.

Another form of decision support is provided by selecting option U. This enables the display of any individual alternative. In Figure 8.12b, I present the display that results from selection of the lipoprotein proposal. The profile provides a concise evaluation of the proposal. Team competence, facilities, and cost factors are evaluated as outstanding, scientific merit of the

**Figure 8.12**
**Overall Rankings vs. Evaluation of Selected Proposals**

Figure 12a.

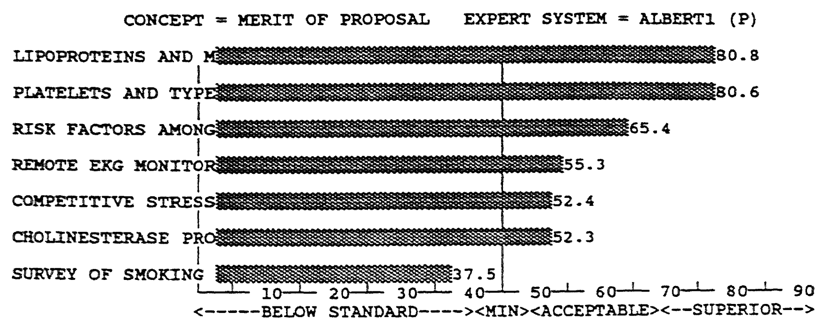
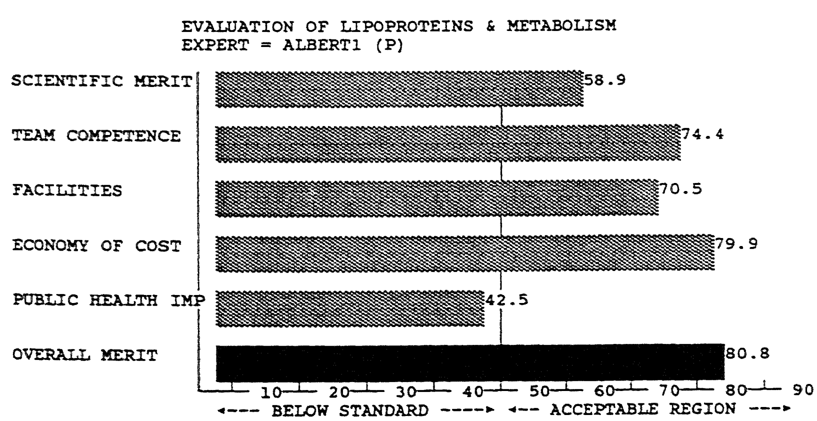



Figure 12b.




*Note:* Evaluation of the overall merit of all proposals is shown in the top panel. The bottom panel displays the evaluation of all concepts of a specific proposal selected by the user (lipoproteins & metabolism).

proposal is acceptable, although the public health impact is marginal. Aggregating over the five concept scores yields the overall evaluation of 80.8 for this proposal. This is shown as the solid bar graph at the bottom of Figure 8.12b.

It is of interest that the overall rating of 80.8 is higher than the ratings of any of the five concepts on which it is based. Why should this be? To address this question, note first that the derived overall ratings are on an absolute scale, with a precise designation of the passing point. As with other parameters of the expert systems, the passing point is derived mathematically from information collected during the policy-capturing phase. It is therefore an accurate reflection of the standards of the experts selected by the user. From the heading at the top of Figure 8.12b we see that the overall evaluations are based exclusively on Albert's expert system, although the evaluations of the component concepts shown in the figure are based on different combinations of experts.

By referring to the first record of Figure 8.9, we see that the standards of Albert (28.0) are lenient, in contrast, say, to the standards of Evelyn (75.0). In this example, the user chose to override the software's algorithm for the aggregation of the expertise of multiple stakeholders and chose instead to select Albert for the top-level evaluation. As a result, the overall evaluations of all proposals displayed in Figure 8.12a were high, and one result of this was an overall rating of 80.8 for the lipoprotein proposal.

Had the user elected to permit the expert system aggregation algorithm to be invoked, the algorithm would have recognized the leniency inherent in Albert and Laura's standards and would have given more weight to Evelyn's point of view. That would have resulted in a downward shift in the cutting score by a constant amount. The relative rankings of the proposals would have remained unchanged, but all proposals would have fared more poorly.

## SUMMARY

This chapter began with a distinction between rule-based and function-based expert systems. Some important limitations of rule-based expert systems were noted. The main thrust of the chapter has been to clarify, by both discussion and example, the methodology underlying function-based expert systems and their application to program evaluation.

Rule-based expert systems have, until now, been clearly dominant and have been used in many contexts with considerable success. However, there are many classes of problems for which these systems are ill suited and for which function-based expert systems can be employed to advantage.

The versatility of function-based expert systems was noted, including their usefulness to integrated decision support systems. These tools provide users with considerable flexibility. They assist in the evaluation of alternatives within the framework of standards and values of individual stakehold-

ers, and they are able automatically to aggregate the expertise of their stakeholders on a rational basis.

The variety of feedback that becomes possible through adoption of function-based expert systems can be presented with clarity in the form of screen displays. These displays can enable an organization to develop a more comprehensive understanding of the process by which decisions are made among competing alternatives. At the same time, they offer stakeholders insights into the basis for their various points of view. It should also be noted that function-based evaluation systems convert a heretofore subjective process of decision making into one that is completely rational, while preserving, in their data files, the algebraic functions that form the basis of the decisions. This offers organizations a high degree of audit control over its decision-making functions, enabling an objective justification of decisions when required.

The most advantageous areas for application of function-based expert systems are in committee and organizational decision making. It is in this domain that it becomes vital both to understand the orientations and standards of individual decision makers and to aggregate disparate orientations and standards in a cohesive and rational manner. Program evaluation, proposal evaluation, budgeting, and personnel decision making represent some of the more obvious challenges for application of function-based expert systems.

## NOTE

1. The examples presented in this chapter are fictitious. No implication is intended concerning the specific factors NIH committees might consider in their evaluations of proposals.

## REFERENCES

Dawes, R. M. (1971). A case study of graduate admissions: Application of three principles of human decision making. *American Psychologist, 26,* 180–188.

Ebert, R. J., and T. E. Kruse. (1978). Bootstrapping the security analyst. *Journal of Applied Psychology, 63,* 110–119.

Hammond, K. R., G. H. McClelland, and J. Mumpower. (1980). *Human judgment and decision making.* New York: Praeger Publications.

Harmon, P. (1985). Tools. *Expert Systems Strategies, 1*(1).

Hayakawa, S. I. (1947). Meaning, symbols and levels of abstraction. In T. M. Newcomb and J. Hartley (eds.), *Readings in social psychology.* New York: Henry Holt & Co.

Hoffman, P. J. (1960). The paramorphic representation of clinical judgment. *Psychological Bulletin 57*(2), 116–133.

———. (1985). Quasi-artificial intelligence and expert systems. COGITAN Research Report 6. Los Altos, Calif.: Magic7 Software Co.

———. (1991). Technical notes and background for users of EXPERT87. Cogitan Research Reports. Los Altos, Calif.: Magic7 Software Co.

Hoffman, P. J., P. Slovic, and L. G. Rorer. (1968). An analysis of variance model for the assessment of configural cue utilization in clinical judgment. *Psychological Bulletin, 69,* 338–349.

Hogarth, R. (1980). *Judgment and choice: The psychology of decision.* New York: Wiley.

McNemar, Q. (1949). *Psychological statistics.* New York: Wiley.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63,* 81–97.

Ramanaiah, N. V., and L. R. Goldberg. (1977). Stylistic components of human judgment: The generality of individual differences. *Applied Psychological Measurement, 1,* 23–29.

Slovic, P., and S. Lichtenstein. (1971). Comparison of Bayesian and regression approaches to the study of information processing in judgment. *Organizational Behavior and Human Performance, 6,* 649–744.

Smith, P. C. (1983). The problem of criteria. In M. D. Dunnette (ed.), *Handbook of industrial and organizational psychology,* pp. 745–775. New York: Wiley.

9

# Knowledge-based Explanation in Multiattribute Decision Making

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In general, the decision-making problem can be defined as follows:

*Given* a set of alternatives $A = \{a_1, a_2, \ldots\}$ and (somehow expressed) aims or goals of the decision maker,
*find* alternative $a_i \in A$ that best satisfies the goals.

Problems of this kind can be found in almost any field of human activity, ranging from everyday personal decisions to more complex problems in economy, management, and medicine. The complexity of such problems usually originates in:

- Complex and often incomplete, uncertain, or conflicting knowledge of how to define and achieve the goals.
- Numerous and/or loosely defined alternatives.
- A large number of parameters that influence the decision.
- The presence of several decision-making groups with different objectives.
- Time constraints and other resource limitations imposed on the decision-making process.

A number of methods and computer programs have been developed to support decision makers in solving more or less complex decision problems (Humphreys & Wisudha 1987). They are usually studied within the framework of decision support systems (Keen & Scott Morton 1978; Alter 1980), operations research and management sciences, decision theory (French 1986), or decision analysis (Phillips 1986). In a broad sense, expert systems, which originate in artificial intelligence, can also be considered systems that

solve and explain complex, repetitive decisions (Efstathiou & Mamdani 1986; Turban 1988; Klein & Methlie 1990).

In this chapter we show how multiattribute decision-making methods can be combined with expert systems—in particular how to support explanation and analysis of decisions.

## MULTIATTRIBUTE DECISION MAKING

In multiattribute decision making, the decision problem is decomposed into smaller, less complex subproblems (Keeney & Raiffa 1976; Chankong & Haimes 1983; French 1986). Such subproblems are represented by a set of criteria (or attributes) $X = \{\chi_1,\chi_2, \ldots, \chi_n\}$. Criteria are variables that take values from the corresponding value domains $\chi_1,\chi_2, \ldots \chi_n$.

Each alternative $a \in A$ is measured and described by a vector of values

$$a = \langle v_1, v_2, \ldots, v_n \rangle, \quad v_i \in X_i, \quad i = 1, 2, \ldots, n.$$

The alternative is then evaluated, usually in two steps. First, the decision maker's preferences $p_i$ of $a$ according to each separate criterion $x_i$ are obtained:

$$p_i = f_i(v_i), \qquad i = 1, 2, \ldots, n.$$

Here, $f_i$ is a partial utility function defined by the decision maker for each $\chi_i$. The preferences $p_i$ are usually expressed as numbers on a certain interval, for example [0,1].

The total utility of $a$ is finally aggregated by the function $F$:

$$u(a) = F(p_1, p_2, \ldots, p_n).$$

In practice, $F$ is most commonly expressed as a weighted sum where weights $w_i$ are defined by the decision maker:

$$F(p_1, p_2, \ldots, p_n) = \sum_{i=1}^{n} w_i \, p_i .$$

The alternatives are finally ranked according to the total utilities. In general, the alternative with the highest utility should be selected as the best one.

Note, however, that only the main ideas of multiattribute decision making have been presented; the details are treated quite differently in different methods. For example, criteria may be additionally structured into trees. There are also considerable variations in the representation and assessment of alternatives and utility functions (French 1986; Humphreys & Wisudha 1987).

The most common drawback of existing multiattribute methods, at least for some classes of problems, is the need to translate the decision makers' knowledge about a decision problem into numbers and functions. Experience with expert systems (Turban 1988; Klein & Methlie 1990) indicates that this is not always necessary. There are decision problems in which qualitative judgment prevails over more or less exact quantitative evaluation. For such problems, it is quite a natural choice to use models that incorporate qualitative elements as well, for example, qualitative (descriptive, linguistic, ordinal) variables and rules. Expert system applications have confirmed that such an approach is not only feasible but can also provide some valuable features: explicit and flexible knowledge representation (Fox 1985), transparency (Levine, Pomerol & Saneh 1990), natural language dialogues (Vari & Vecsenyi 1988), and explanation of reasoning (Efstathiou & Mamdani 1986).

In the following sections we show how explanation facilities can be gained by combining multiattribute and expert system paradigms. The proposed approach is based on an explicit articulation of knowledge about a particular decision-making problem. Knowledge representation is specific and oriented toward multiattribute problems. It consists of tree-structured criteria and utility functions that are represented by rules rather than formulas.

## KNOWLEDGE REPRESENTATION

Knowledge representation for multiattribute decision making is based on a tree of criteria $T = (X, S)$, where:

$X$ is a set of criteria $\{\chi_1, \chi_2, \ldots, \chi_n\}$; each criterion $x_i$ may take values from the corresponding value domain $X_i$.

$S$ is a mapping from $X$ to the power set of $X$. For each criterion, $S$ defines the set of its immediate descendants (sons) in the tree. Only such mappings $S$ are permitted that structure criteria into a single (connected) tree whose root is $\chi_1$.

Criteria $\chi$ for which $S(\chi) = \emptyset$ are leaves of the tree. They are also referred to as basic criteria. The remaining ones are called aggregate criteria.

Domains $X_1, X_2, \ldots, X_n$ are assumed to be discrete and finite. They generally consist of words, not numbers; words such as *good* or *low* can be used. Numerical qualities can be expressed as intervals of values; each interval is treated as a discrete domain element. It is also recommended to order domain elements by preference from "bad" (nonpreferred) to "good" (highly preferred) values, for example {*bad, acceptable, good, excellent*} or, for price, {*high, medium, low*}.

The tree of criteria represents the structure of a particular decision problem. The purpose of the second component of the decision knowledge base, utility functions, is to define the relation between aggregate criteria and their

descendants in the tree. For each aggregate criterion $\chi_k$, the corresponding utility function

$$F_k : X_{k1} \times X_{k2} \times \ldots X_{k_m} \rightarrow X_k$$

should be defined by the decision maker. Here, $X_{k_1}, \ldots, X_{k_m}$ denote the value domains of all the descendants of $\chi_k$.

When different decision groups with different interests are involved in the decision-making process, each group may define its own set of utility functions. Therefore, more than one function can be defined for each aggregate criterion, as shown in Figure 9.1.

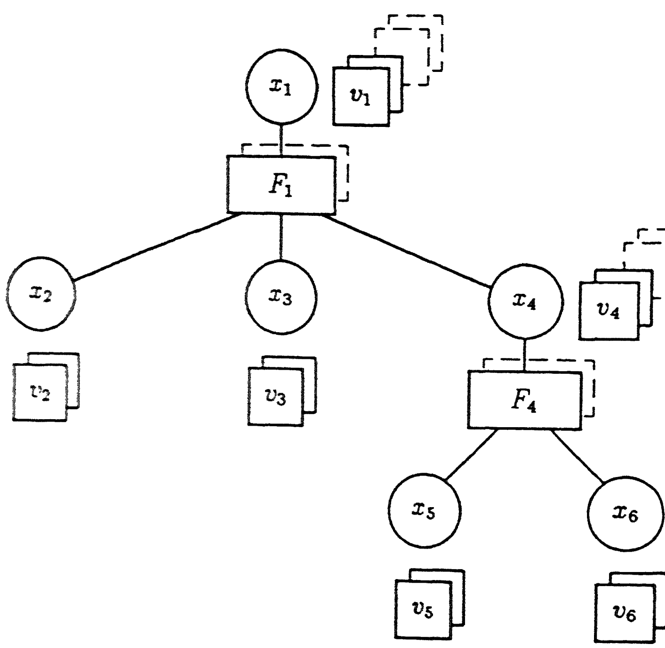
Utility functions $F_k$ are represented by elementary decision rules of the form

$$if\ \chi_{k_1} = v_{k_1}\ and \ldots and\ \chi_{k_m} = v_{k_m}\ then\ \chi_k = v_k,$$

where $v_{k_i}$ and $v_k$ denote single values taken from domains $X_{k_i}$ and $X_k$, respectively.

The consistency of rules is required. This means that the rules should be unique with respect to their conditional parts. On the other hand, the com-

**Figure 9.1**
**Criteria Tree with Utility Functions and Alternatives**



pleteness of rules is not required, meaning that for some combinations of values $v_{k_1}, \ldots, v_{k_m}$ there might be no corresponding rules. The set of rules that correspond to a particular aggregate criterion is usually represented in a tabular form (see, for example, Table 9.2).

After the criteria tree and utility functions have been defined, the evaluation of alternatives can start. The alternatives are first measured and described by values of basic criteria. The utility functions are then applied in a bottom-up manner in order to obtain aggregate values for each alternative. These values, particularly the one that has been assigned to the root, are finally used to select the best alternative.

Figure 9.1 illustrates a decision knowledge base after alternatives have been evaluated. There are two aggregate criteria, $\chi_1$ (the root) and $\chi_4$. The corresponding utility functions are $F_1$ and $F_4$. Note that in the presence of different decision-making groups, more than one function can be defined for each aggregate criterion.

There are two alternatives shown in Figure 9.1. They are described by values $v_2$, $v_3$, $v_5$, and $v_6$ that are assigned to basic criteria $\chi_2$, $\chi_3$, $\chi_5$, and $\chi_6$. Evaluation results $v_4$ and $v_1$ for each alternative have been obtained by functions $F_4$ and $F_1$, respectively. The evaluation is performed separately for each decision-making group. Therefore, when there are more groups, a set of evaluation results, consisting of $v_4$ and $v_1$, is obtained for each group.

An example of a real-world criteria tree is shown in Figure 9.2. The tree was designed in a project whose goal was to evaluate microcomputers with respect to their appropriateness for education in primary and secondary schools of the Republic of Slovenia (Rajkovič et al. 1985). Figure 9.2 actually presents only the subtree that was used to evaluate microcomputer hardware. The whole tree, which additionally included software and commercial criteria, was about twice as big. In Figure 9.2, aggregate and basic attributes are represented by uppercase and lowercase letters, respectively, and followed by the corresponding value domains. According to the tree, microcomputer Hardware is determined by three main groups of criteria: Environment, Processor, and capabilities to Upgrade the system. The first two are additionally decomposed. For example, the Environment is decomposed into Basic Communication, Peripherals, and Connections.

Table 9.1 presents a simple set of elementary rules that define Basic Communications according to the quality of Monitor and Keyboard. Note the incompleteness of this table: some combinations of values of Monitor and Keyboard, for example Monitor = *good* and Keyboard = *good,* are undefined in the table.

The approach presented in this section has been implemented within an expert system shell DECMAK (Bohanec, Bratko & Rajkovič 1983; Bohanec & Rajkovič 1987; Rajkovič, Bohanec & Batagelj 1988) and thoroughly verified in practice. The shell interactively supports the decision maker in the knowledge acquisition and evaluation stages of the decision-making process.

**Figure 9.2**
**Criteria Tree for the Evaluation of Microcomputer Hardware**

- HARDWARE — *unaccept, accept, good, exc*
  - ENVIRONMENT — *unaccept, accept, good*
    - BAS_COMM — *unaccept, accept, good*
      - monitor — *unaccept, accept, good*
      - keyboard — *unaccept, accept, good*
    - PERIPH — *unaccept, accept, good*
      - printer — *unaccept, accept, good*
      - EXT_MEM — *unaccept, accept, good*
        - cassettes — *no, yes*
        - disk — *none, accept, good*
      - add_periph — *no, yes*
    - CONNECTIONS — *unaccept, accept, good*
      - loc_network — *none, accept, good*
      - INTERFACE — *unaccept, accept*
        - std_interf — *no, yes*
        - a/d_conv — *no, yes*
  - upgrade — *bad, accept, good*
  - PROCESS — *unaccept, accept, good*
    - GRAPHICS — *unaccept, accept, good*
      - bw_graph — *unaccept, accept, good*
      - col_graph — *none, accept, good*
      - characters — *unaccept, accept, good*
    - memory — *unaccept, accept, good*

It is beyond the scope of this chapter to describe the knowledge acquisition techniques that are used in DECMAK. They are based on an interactive dialogue for the acquisition of elementary decision rules. Additional tools are available that present the whole knowledge base to the decision maker using different viewpoints and levels of detail (Rajkovič, Bohanec & Batagelj 1988; Bohanec and Rajkovič 1987, 1988).

The following sections are focused on techniques and algorithms used in DECMAK to support the evaluation stage of the decision process. In this

**Table 9.1**
**Elementary Decision Rules for Basic Communications**

| MONITOR | KEYBOARD | BAS_COMM |
|---|---|---|
| *unaccept* | *unaccept* | *unaccept* |
| *unaccept* | *good* | *unaccept* |
| *accept* | *accept* | *accept* |
| *accept* | *good* | *accept* |
| *good* | *unaccept* | *unaccept* |
| *good* | *accept* | *good* |

stage, the evaluation of alternatives, explanation of results, and analysis of alternatives take place.

## EVALUATION OF ALTERNATIVES AND EXPLANATION OF RESULTS

In this stage of the decision-making process, the knowledge base, which we assume has been defined and verified in the previous stages, is used to evaluate alternatives. At the beginning, the decision maker describes each alternative $a \in A$ by a vector of values that correspond to all basic attributes $\chi_{b_1}, \chi_{b_2}, \ldots, \chi_{b_m}$:

$$a = \langle v_{b_1}, v_{b_2}, \ldots, v_{b_m} \rangle, \quad v_{b_i} \in X_{b_i}, \quad i = 1, 2, \ldots, m.$$

In DECMAK, these descriptions are entered interactively, using a spreadsheet-like editor of alternatives.

DECMAK is also capable of handling incomplete and uncertain data about alternatives by means of probabilistic and fuzzy distributions of values (Bohanec, Bratko & Rajkovič 1983). For simplicity, this feature is omitted from the following presentation.

After the alternatives have been described, they are evaluated by DECMAK. The evaluation proceeds from the bottom to the top of the criteria tree. The value $v_i$ of each aggregate criterion $\chi_i$ is obtained by evaluating the corresponding utility function $F_i$. The function arguments are the values $v_{i_j}$ that are assigned to all the descendants of $\chi_i$ in the tree:

$$v_i = F_i(v_{i_1}, v_{i_2}, \ldots), \quad v_{i_j} \in X_{i_j}.$$

In order to evaluate $F_i$, DECMAK searches for the decision rule that exactly matches the arguments. If such a rule exists, it directly assigns the value to $v_i$. Otherwise, the regression analysis is applied over some of the remaining rules. Only the rules that slightly differ from the arguments of the function are considered. The Euclidean distance is used as a heuristic measure of difference between rules.

The evaluation of alternatives assigns values (utilities) to all the aggregate criteria in the tree. These values determine the adequacy of each alternative according to the decision maker's preferences. The alternative that has the most desirable values should be chosen.

Some important questions usually emerge at this point:

- How were the results obtained? Why they are such? Are they appropriate?
- Are the results influenced by changes of basic criteria values, and how? Which changes are required in order to get a better (or worse) alternative?

- What are the advantages and disadvantages of a particular alternative? How does it compare to some other alternative?

The evaluation results themselves are insufficient to answer these questions. Additional tools that help the user to explain, justify, and analyze the decision are needed. As shown below, the rule-based approach offers quite useful support for such tasks.

Obviously, the evaluation process itself can be easily explained in terms of decision rules that have been triggered and criteria values that have been used. This is similar to the How? type of explanation in expert systems.

There is, however, a problem with the explanation of results obtained by the regression analysis. Due to its inherent "black box" functioning, it is difficult to explain the computation itself. However, since it operates on a limited set of rules (usually, two to five), these rules are shown to the user. According to our experience, the users are able to justify the appropriateness of the computation on the basis of this implicit information.

With DECMAK, the evaluation and explanation are performed interactively. The user can focus attention on particular aggregate criteria, inspect and/or change rules, and follow the detailed explanation. This is often combined with what-if analysis, where the user changes descriptions of particular alternatives, reevaluates them, and compares the results with the original ones.

## SELECTIVE EXPLANATION AND COMPARISON OF ALTERNATIVES

The explanation described above answers the question: How were the results obtained? Its main role is to present a detailed overview of the evaluation process and to help the user in discovering errors in the knowledge base and descriptions of alternatives. However, there is a question that is usually more important in practice: Why are the results such? Unfortunately, the ultimate answer is hidden in rules; they are basic facts that can be meaningfully explained only by the person who defined them.

Nevertheless, some implicit and practically important answers can be gained by exploring the evaluation results and relations among them. For example, if an alternative got a bad final utility, one might be interested in sources (i.e., basic criteria values) that caused this result. For a better overview of an alternative, it is also useful to find its most important advantages.

For this purpose, a selective explanation algorithm is used in DECMAK. Its main role is to explain a particular alternative in terms of its most advantageous or disadvantageous characteristics. The explanation is selective because, instead of all, usually quite numerous criteria, only the most relevant ones are shown in the form of subtrees of the whole criteria tree.

This algorithm operates by searching for such maximal connected sub-

trees of the whole criteria tree in which a particular alternative evaluates to very bad or, alternatively, very good. To determine whether a value is very bad or very good, a simple heuristics is used. Since the criteria domains are usually preferentially ordered (95 percent of domains used in about forty practical applications of DECMAK were such), the leftmost element of each domain is considered very bad and the rightmost very good by default. When this is inappropriate, the user is allowed to redefine explicitly the sets of very good and very bad values.

An example of selective explanation is shown in Figure 9.3. The quality of hardware of a particular microcomputer is explained on the basis of the criteria tree from Figure 9.2. The default settings have been used in order to determine very bad and very good values.

Virtually the same algorithm can be used also for the selective comparison of alternatives, which is needed for comparison of two different alternatives, discovering changes of one alternative during the what-if analysis, and comparison of the same alternative that was evaluated by utility functions of different decision-making groups.

**Figure 9.3**
**Selective Explanation of a Microcomputer's Hardware**

Advantages:

COL_GRAPH is *good*

INTERFACE is *accept*
    because STD_INTERF is *yes*
    because A/D_CONV is *yes*

ADD_PERIPH is *yes*

CASSETTES is *yes*

Disadvantages:

HARDWARE is *unaccept*
    because ENVIRONMENT is *unaccept*
        because BAS_COMM is *unaccept*
            because MONITOR is *unaccept*
        because CONNECTIONS is *unaccept*
            because LOC_NETWORK is *none*
    because PROCESS is *unacc*
        because GRAPHICS is *unaccept*
            because BW_GRAPH is *unaccept*
            because CHARACTERS is *bad*

The comparison algorithm differs from the explanation one only in the condition that must be satisfied in all nodes of the extracted subtrees. Here, the condition is satisfied if the first alternative is (strictly) better than the second one or, alternatively, the second one is better than the first. The relation better (represented by > in Figure 9.4) is again determined from the preferentially ordered domains or explicitly given by the user. Figure 9.4 presents an example of selective comparison of two microcomputers.

## OPTION GENERATION

Another important aspect of the analysis and implementation of the decision is to find such small changes in descriptions of an alternative that cause degrading or upgrading its performance. The findings about changes that might degrade the alternative can be particularly useful in the stage of its implementation; once the most critical characteristics have been identified, it is much easier for the implementer to treat them carefully. On the other hand, the information about the changes that upgrade the alternative can serve as a guideline for possible improvements of the alternative.

In DECMAK, such information can be gathered by an option generator. To describe the algorithm, let us concentrate on a single aggregate criterion $y$. Let $\chi_1, \chi_2, \ldots, \chi_k$ be its descendants in the criteria tree. Therefore, the relation between the criteria is that

$$y = F(\chi_1, \chi_2, \ldots, \chi_k).$$

**Figure 9.4**
**Selective Comparison of Two Microcomputers**

**Alternative A is better in:**

BAS_COMM is better (*good* > *accept*)
  because MONITOR is BETTER (*good* > *accept*)

ADD_PERIPH is better (*yes* > *no*)

**Alternative B is better in:**

HARDWARE is better (*exc* > *accept*)
  because PROCESS is better (*good* > *accept*)
    because GRAPHICS is better (*good* > *accept*)
      because BW_GRAPH is better (*good* > *accept*)
      because COL_GRAPH is better (*good* > *none*)

PRINTER is better (*good* > *accept*)

We also assume that an alternative $a \in A$ has been already evaluated on $y$ and denote with

$$\mathbf{v} = \langle v_1, v_2, \ldots, v_k \rangle$$

the vector of values that have been assigned to $\chi_1, \chi_2, \ldots, \chi_k$ for this alternative. Let $u$ be the utility of the alternative, obtained by

$$u = F(\mathbf{v}).$$

The task of the option generator is then to determine the smallest changes $\Delta\mathbf{v}$ of vector $\mathbf{v}$ which would lead to

$$F(\mathbf{v} + \Delta\mathbf{v}) = z,$$

such that $z > u$ for upgrading the alternative or $z < u$ otherwise.

At the beginning, the option generator implicitly completes the table of rules that define $F$ by adding all the missing rules; the regression analysis from the previous section is used for this purpose. Then, the set of all rules that yield the value of $z$ is determined. These are the rules of the form:

$$\textit{if } \chi_1 = w_1 \textit{ and} \ldots \textit{and } \chi_k = v_k \textit{ then } y = z.$$

Each such rule corresponds to the assignment of values

$$z = F(w_1, \ldots, w_k) = F(w).$$

Therefore, $F(w) = F(\mathbf{v} + \Delta\mathbf{v})$, so

$$\Delta\mathbf{v} = w - \mathbf{v}.$$

However, such $\Delta\mathbf{v}$ need not be the smallest one; it should be compared to all the difference vectors that are determined from the remaining rules that assign $y = z$. Therefore, all pairs of rules such that $z = F(w_1)$ and $z = F(w_2)$ are compared by the option generator. When upgrading alternatives, $\Delta\mathbf{v}_1$ that follows from the first rule is eliminated if $w_{1,i} \geq w_{2,i}$ for all $i = 1, 2, \ldots, k$. When finding the smallest changes that degrade alternatives, the above condition is replaced by $w_{1,i} \leq w_{2,i}$.

The extension of this algorithm from one aggregate criterion $y$ to any subtree of $y$ is straightforward: the algorithm should only be applied recursively on all the aggregate descendants of $y$. An example of the option generator output is shown in Figure 9.5. It was generated by applying the above algorithm on rules from Table 9.1. Note, however, that this table is extremely simple, so the output is not as interesting and valuable as when treating more complex tables and subtrees.

**Figure 9.5**
**Output of the Option Generator**

Value 1: MONITOR=*accept*
Value 2: KEYBOARD=*good*
Utility: BAS_COMM=*accept*

BAS_COMM becomes *unaccept*
    if ( MONITOR becomes *unaccept* ) or
    if ( MONITOR becomes *good* and
        KEYBOARD becomes *unaccept* ).

BAS_COMM becomes *good*
    if ( MONITOR becomes *good* and
        KEYBOARD becomes *accept* ).

## APPLICATIONS

The DECMAK system has been applied in about forty practical decision-making problems. They varied from simple, personal decisions, like job or car selection, to complex group decision problems, such as:

1. Evaluating mainframe computer systems (eight applications so far).
2. Selection of computers for schools (four applications).
3. Microcomputer selection.
4. Evaluation of production control software.
5. Database management system selection (two applications).
6. Trading partner selection.
7. Evaluation of applications for nursery schools.
8. Matching people to jobs.
9. Expert team selection.
10. Project feasibility estimation.
11. Performance evaluation of public enterprises.

The first part of the list (applications 1 to 5) indicates that DECMAK has been extensively used in decisions related to computers. The main reason for this is the computer science background of the authors of the system. In these problems, it was convenient for the authors to play a dual role of decision analysts and computer consultants. Nevertheless, the applications numbered 6 to 11 show that the usefulness of DECMAK is not limited to computer-oriented problems. The complexity of a particular decision problem is reflected in the size of the knowledge base and the number of considered alternatives. These data for some of the above problems are presented in Table 9.2.

**Table 9.2**
**The Complexity of Some DECMAK Applications**

| Application | Number of Basic criteria | Number of Aggregate criteria | Number of Alternatives |
|---|---|---|---|
| 1.a | 20 | 9 | 6 |
| b | 67 | 45 | 2 |
| c | 17 | 9 | 3 |
| d | 35 | 24 | 8 |
| 2.a | 11 | 6 | 6 |
| b | 12 | 9 | 10 |
| c | 36 | 19 | 24 |
| 5. | 74 | 29 | 3 |
| 6. | 22 | 12 | >20 |
| 7. | 8 | 5 | >2000 |
| 9. | 16 | 8 | 164 |
| 10. | 34 | 19 | 1 |
| 11. | 12 | 9 | 55 |

## DISCUSSION

One of the main motivations for combining multiattribute decision making with the knowledge-based approach in DECMAK was to improve the quality of decision making by the aid of explanation. There are extremely rare decision situations where the criteria and alternatives are so clear that they directly lead to optimal solutions without any further analysis and explanation. Usually, a great deal of uncertainty and missing information is involved, important criteria may be overlooked or treated inappropriately, and so on. Therefore, the obtained results should not be accepted until they are carefully investigated, justified, and understood by the decision maker.

The proposed approach is based on a structured and explicitly articulated knowledge base that can be argued, verified, and documented. Its structure is especially adapted for multiattribute decision problems. Although the structure is relatively simple compared to common expert systems, it has been found quite general and flexible in practice. In the stage of knowledge acquisition, the main advantages are easy acquisition of elementary decision rules by an interactive human-machine dialogue and powerful capabilities for explaining the whole knowledge base by means of machine learning techniques. These are presented and discussed elsewhere (Bohanec & Rajkovič 1988; Rajkovič & Bohanec 1991).

In the evaluation stage of the decision-making process, the knowledge base is applied consistently to all alternatives in order to obtain and explain their utilities. The evaluation approximately corresponds to reasoning in

common expert systems. However, due to the specifics of the problem, it is much more function oriented; it basically calculates function values. There is no inference based on logic, theorem proving, or anything else. The order of evaluation of rules is strictly determined by the structure of criteria.

In all practical applications of DECMAK, some kind of explanation was needed (and done) in the evaluation stage. Usually at least some of the evaluation results were in disagreement with the decision maker's expectations. It was necessary to investigate them in more detail and find out the reasons for the disagreement, which could have been caused by erroneous rules, inappropriate descriptions of alternatives, overlooked criteria, or wrong expectations. In this respect, the explanation by tracing the triggered rules has been found useful but not as much as we had originally expected. It was invoked quite rarely, mainly to explain unexpected values assigned to a single aggregate criterion. In our opinion, the main reason for this is in low and nonselective informativity of this kind of explanation. The decision maker is usually at the same time the author and user of the rules. For this reason, the triggered rules hardly provide any new information for him or her.

In order to discuss alternatives within the decision-making group and to justify the decision, an overall (aggregate) explanation of each alternative is needed. In practice, it seems that the selective explanation algorithm suits extremely well for this purpose. It was used in all practical decision problems. The decision makers considered it an important support tool for the explanation and verification of the decision. Its results were also very useful in preparing reports and other presentations related to the decision. Usually, only the translation of the printouts (such as the ones in Figure 9.3) into ordinary sentences was sufficient to provide a comprehensible explanation.

The main power of the selective explanation is in its ability to extract and group together the criteria and values that most relevantly determine the quality of a particular alternative. However, in the current implementation of DECMAK, the "relevance" of criteria is determined by a simple heuristic inspection of criteria domains. Further research is suggested at this point to find more general and robust measures of relevance, for example, by taking into account the underlying utility functions.

The option generator is usually applied after a limited set of possible candidates for the best alternative has been identified. These are then thoroughly analyzed, mainly to isolate critical characteristics that can easily degrade them in the implementation stage. When the decision makers are in a position to influence the alternatives, for example, to require some modifications of computer hardware from the distributor, the possibilities of upgrading them are also interesting for investigation. According to our experience, the usefulness of the option generator heavily depends on the decision problem. There were problems where it was not needed at all, for example, in selecting an expert team and evaluating application for nursery schools. Its role was more important in decisions related to computers and

public enterprises. However, there was a problem when a decision had to be made as to whether to continue or abandon a large software development project. All aspects of this project were thoroughly analyzed almost exclusively by the option generator.

## CONCLUSION

The decision-making approach presented in this chapter combines two techniques, multiattribute decision methods and expert systems. It is based on an explicit articulation of knowledge about a particular decision problem. The knowledge is represented by tree-structured criteria and utility functions, defined by elementary decision rules.

The approach is supported by an expert system shell, DECMAK, consisting of tools that support interactive knowledge acquisition and evaluation of alternatives. The main emphasis is on the explanation and analysis of the evaluation process.

DECMAK has been verified in about forty practical decision-making situations. The results confirmed the importance of the explanation facilities. Their availability motivated the decision makers to think about, verify, justify, and explore decisions. We strongly believe this is one of the key elements that can improve the effectiveness and justification of decisions.

Among the algorithms presented in this chapter, the selective explanation one has been found the most valuable in practice. Its main advantage is the ability to explain alternatives by selecting only the most relevant information and presenting it to the user in a structured form.

## REFERENCES

Alter, S. L. (1980). *Decision support systems: Current practice and continuing challenges.* Reading, Mass.: Addison-Wesley.

Bohanec, M., I. Bratko, and V. Rajkovič. (1983). An expert system for decision making. In H. G. Sol (ed.), *Processes and tools for decision support.* Amsterdam: North-Holland.

Bohanec, M., and V. Rajkovič. (1987). An expert system approach to multiattribute decision making. In M. H. Hamza (ed.), *Proceedings of IASTED conference on expert systems.* Anaheim, Calif.: Acta Press.

Bohanec, M., and V. Rajkovič. (1988). Knowledge acquisition and explanation for multi-attribute decision making. *Proceedings of the Eighth International Workshop, Expert Systems and Their Applications,* vol. 1. Avignon.

Chankong, V., and Y. Y. Haimes. (1983). *Multiobjective decision making: Theory and methodology.* Amsterdam: North-Holland.

Efstathiou, J., and E. H. Mamdani. (1986). Expert systems and how they are applied to industrial decision making. In G. Mitra (ed.), *Computer assisted decision making.* Amsterdam: Elsevier.

Fox, M. S. (1985). Knowledge representation for decision support. In L. B. Methlie

and R. H. Sprague (eds.), *Knowledge representation for decision support systems.* Amsterdam: North-Holland.

French, S. (1986). *Decision theory: An introduction to the mathematics of rationality.* New York: Wiley.

Humphreys, C. P., and D. A. Wisudha. (1987). *Methods and tools for structuring and analysing decision problems.* Technical Report 87-1. London: London School of Economics and Political Sciences.

Keen, P.G.W., and M. S. Scott Morton. (1978). *Decision support systems: An organizational perspective.* Reading, Mass.: Addison-Wesley.

Keeney, L. R., and H. Raiffa. (1976). *Decisions with multiple objectives: Preferences and value tradeoffs.* New York: Wiley.

Klein, M., and L. B. Methlie. (1990). *Expert systems: A decision support approach.* Reading, Mass.: Addison-Wesley.

Levine, P., M. J. Pomerol, and R. Saneh. (1990). Rules integrate data in a multicriteria decision support system. *IEEE Transactions on Systems, Man, and Cybernetics, 20,* 678–686.

Phillips, L. D. (1986). Decision analysis and its applications in industry. In G. Mitra (ed.), *Computer assisted decision making.* Amsterdam: Elsevier.

Rajkovič, V. et al. (1985). *Evaluation of microcomputers for primary and secondary schools in Slovenia* (in Slovene language). Ljubljana: Zavod SR Slovenije za solstvo.

Rajkovič, V., M. Bohanec, and V. Batagelj. (1988). Knowledge engineering techniques for utility identification. *Acta Psychologica, 68,* 271–286.

Rajkovič, V., and M. Bohanec. (1991). Decision support by knowledge explanation. In H. G. Sol and J. Vecsenyi (eds.), *Environments for supporting decision processes.* Amsterdam: North-Holland.

Turban, E. (1988). *Decision support and expert systems.* New York: Macmillan.

Vari, A., and J. Vecsenyi. (1988). Concepts and tools of artificial intelligence for human decision making. *Acta Psychologica, 68,* 217–236.

# Part Five

# General Applications and Utilization

# 10

# Decision-Aiding Software for Group Decision Making

Floyd Lewis

## COLLABORATIVE WORK SUPPORT

Modern organizations increasingly are using groups to make decisions and carry out tasks. Researchers have estimated that top management may spend up to 80 percent of their time in meetings (Mintzberg 1971; Van de Ven 1973), clearly a major commitment of resources for a typical company. Most expect that this trend will continue for the foreseeable future.

In the past few years, there has been a notable increase in the attention given to the computer support of work that involves groups. Researchers have addressed many aspects of group work, such as project scheduling, document preparation, communications, and decision-making meetings. A variety of computer-based systems now exist to support many of these activities. (For a collection of papers on collaborative work support, see Greif 1988.) This chapter will focus on a specific system, MeetingWare, designed to support small groups engaged in face-to-face decision-making meetings.

### Problems in Group Decision Making

Groups have encountered many well-documented difficulties in trying to work together to solve problems and make decisions: an overemphasis on social-emotional rather than task activities (Delbecq, Van de Ven & Gustafson 1975), failure to define a problem adequately before rushing to judgment (Maier & Hoffman 1960), pressures for conformity that can reduce creativity and result in "groupthink" (Chung & Ferris 1971; Janis 1981), and deindividuation and diffusion of responsibility that may lead to risky decisions (Diener 1980; Latane, Williams & Harkins 1979).

**Group Decision Support Systems**

Over the years, researchers have developed a variety of techniques to try to overcome these difficulties. Brainstorming (Osborn 1963) and nominal group technique (Delbecq, Van de Ven & Gustafson 1975) are familiar examples of typical structured approaches to group decision making. Recent attempts to integrate some of these techniques with computer technologies have resulted in the creation of a new set of computer-based tools, group decision support systems (GDSS). Huber (1984) has defined a GDSS as "software, hardware, and language components and procedures that support a group of people engaged in a decision-related meeting." A representative sample of recent GDSS research includes papers by Bostrom (1991), Dennis et al. (1988), Dennis, Nunamaker, and Vogel (1990–1991), Easton et al. (1990), Ellis, Rein, and Jarvenpaa (1989–1990), Grohowski et al. (1990), Jessup, Connolly, and Galegher (1990), Keleman, Garcia, and Lewis (1989), Lewis and Keleman (1990), Lewis, Keleman, and Garcia (1990), McGoff et al. (1991), Nunamaker et al. (1989), Sanders, Cerveny, and Wang (1991), Tan, Wei, and Raman (1991), Venkatesh and Wynne (1991), and Vogel et al. (1989–1990).

DeSanctis and Gallupe (1985) have identified four types of GDSS based on proximity (close versus dispersed) and duration of the session (limited versus ongoing). They call a GDSS for meetings of limited duration where members are in close proximity (face-to-face) a *decision room* approach. If the participants are still relatively close together (in the same building) but the session is ongoing, they call it a *local decision network*. A GDSS designed for meetings of limited duration where participants are dispersed is classified as *teleconferencing*. Finally, GDSS for dispersed meetings of an ongoing nature are termed *remote decision making*.

Another characteristic that may vary between GDSS technologies is the size of the group they are designed to support. Most seem to focus on groups of fewer than ten members, but some have been used with larger groups, such as the planning groups using the University of Arizona's MIS Planning and Decision Laboratory, which were reported to exceed twenty members (Nunamaker, Applegate & Konsynski 1987).

The GDSS described in this chapter, MeetingWare, would be classified as a decision room approach by DeSanctis and Gallupe (1985). We designed MeetingWare for face-to-face interaction in sessions of limited duration, though several sessions may be needed to reach a decision. It is also a system best suited for small group use, where there are ten or fewer participants in any one meeting (although up to twenty participants are allowed by the software).

Only a few GDSS systems have been developed to support face-to-face meetings. While most of these have been primarily used in laboratory settings, a few early field studies are now available (for example, see Dennis, Nunamaker & Vogel 1990–1991; Lewis & Keleman 1990; and Nunamaker et

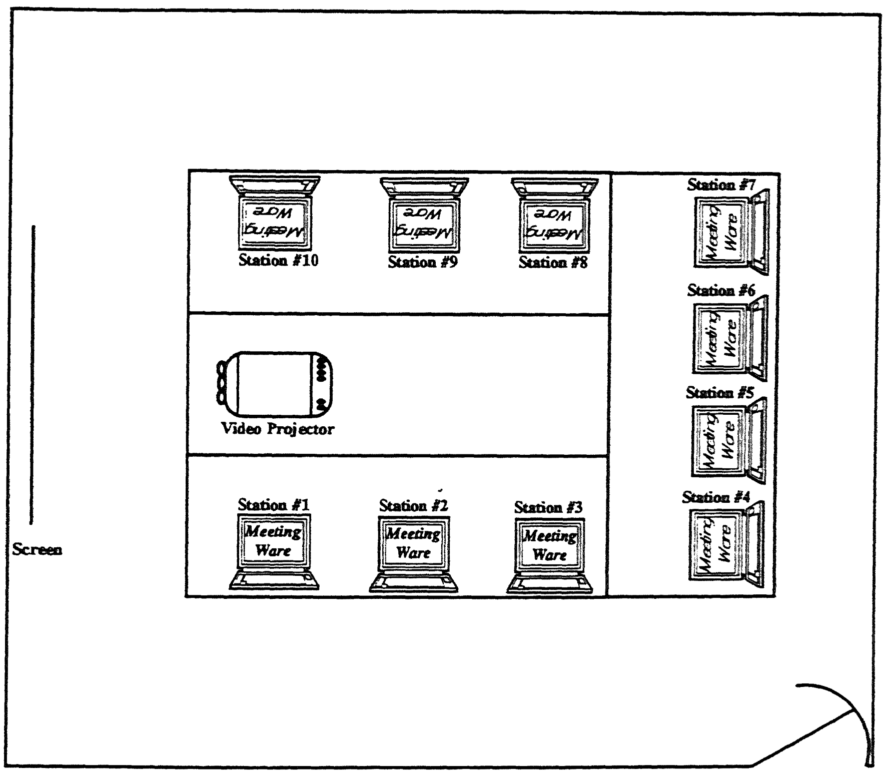
al. 1989). While MeetingWare does have some unique features, for the most part it is representative of the approaches used by the majority of GDSS developers at this time.

## SYSTEM DESCRIPTION

The MeetingWare GDSS is typically installed in a decision room especially arranged for small group meetings (Figure 10.1). A typical decision room has five to ten microcomputers arranged on tables in a U or horseshoe shape, connected by a LAN (local area network). Laptop personal computers (PCs) are ideal for this application; their small size makes them unobtrusive in a meeting and nonthreatening to novices. In addition, it makes the system portable. Sessions can be moved to a client's location or a conference facility or retreat.

The group participants generally directly use all but one of the microcomputers as personal workstations. A more powerful micro provides the net-

**Figure 10.1**
**MeetingWare Decision Room**



work shared disk and is used by the meeting "chauffeur" (a person trained in using the MeetingWare system). This system collects the inputs from individual participants and combines them into a group product. In addition to the chauffeur, there may be a group "facilitator" who may have worked with the group to design the script and who may remain with the group to help them with discussions and process questions. Typically, the facilitator does not use a micro during the meeting unless he or she is filling the role of chauffeur as well.

While all the PCs are connected as a LAN, the chauffeur station is also connected to a display device like a video projector or an LCD plate for use with overhead projectors. This allows information to be displayed to the group on a screen or white wall at the front of the room. When using some MeetingWare tools, a second PC is connected to another display device, so that two displays can be shown simultaneously. A printer is connected to the chauffeur station to provide hard-copy records of the group's activities as they proceed through the script. Typical output would be lists of ideas, ratings, graphs, and summary charts and tables. Participants no longer have to wait several days until someone types up the minutes to have a written record of their decisions.

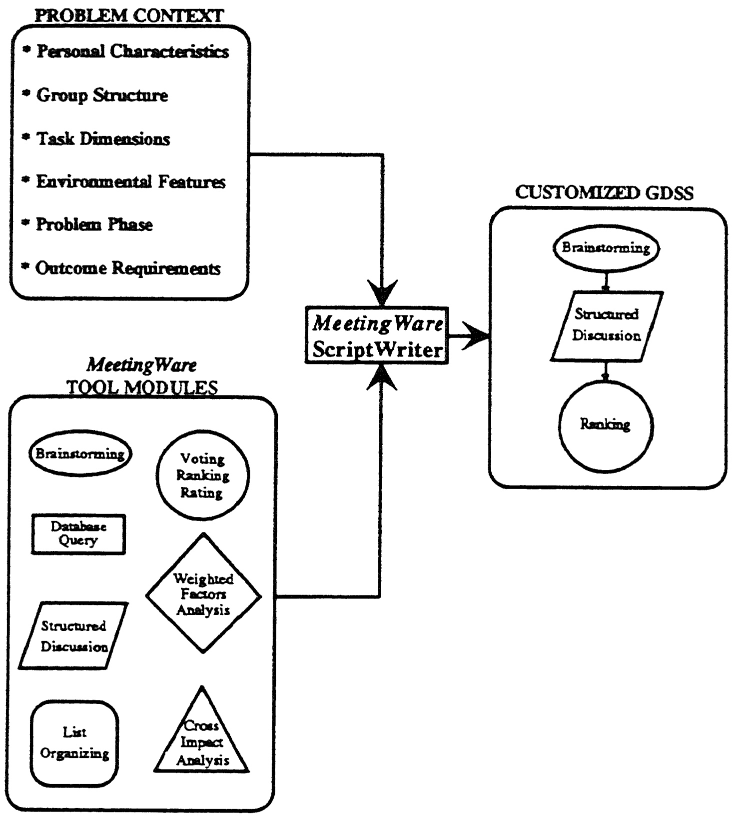
MeetingWare has been under development for ten years. It has evolved from an earlier GDSS called FACILITATOR, built at the University of Louisville in the early 1980s. MeetingWare now consists of an expandable set of modules that users can flexibly combine in a variety of ways to meet the needs of a specific group with a particular problem or decision. The process of selecting modules and integrating them into a particular sequence we call "script writing." With the support of a MeetingWare tool module, script writing allows a meeting manager to specify all the GDSS tools that the group will use in a meeting ahead of time, along with the tool content and the sequence in which they will use the tools. This script is saved as a file; during an actual meeting session, the script is simply executed in order to call up the tools in the proper order. This process is shown in Figure 10.2.

The current set of MeetingWare modules can be divided into six major categories: idea generation, idea discussion, idea organization, idea evaluation, information sharing, and session management. The Symphony software package from Lotus and the QuickBasic language from Microsoft were used for generating the GDSS modules.

### List Generation

There are two modules that a group can use for the purpose of generating a list of ideas: LIST and BRAINSTORM. The LIST module allows each participant to enter up to three ideas on a private screen. Participants work independently and do not see anyone else's ideas during idea generation. The individual lists are combined and saved in a master file that can then be

Figure 10.2
Script Writing in MeetingWare




used by other modules (for discussion, editing, or organization). This module is used when independent thought is a desired feature.

The BRAINSTORM module takes a different approach. Participants initially enter ideas on their own screens, but these ideas are immediately sent to a common file and displayed on the main screen at the front of the room where everyone can read them. The combined file can serve as input to other modules, in the same fashion as the LIST file. This approach is generally used when the group wants to piggyback off each other's ideas.

It is also possible to use a modified approach with BRAINSTORM, when the front screen is not turned on until everyone has entered one or more ideas. This approach has the advantage of initial independent idea generation while retaining the possibility for piggybacking later in the process.

Typical LIST and BRAINSTORM screens are shown in Figures 10.3 and 10.4.

### List Discussion

There are two modules in this category: DISCUSS and COMMENT. Research on group decision making has shown that ideas at the top of a list often receive much more discussion time than ideas on the bottom (Delbecq et al. 1975). This is closely related to the "valence of solutions" concept as

**Figure 10.3**
**MeetingWare List Module**

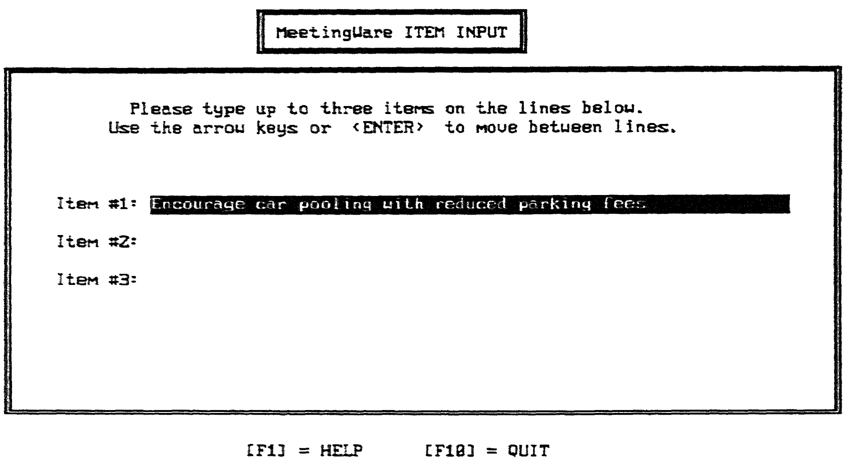
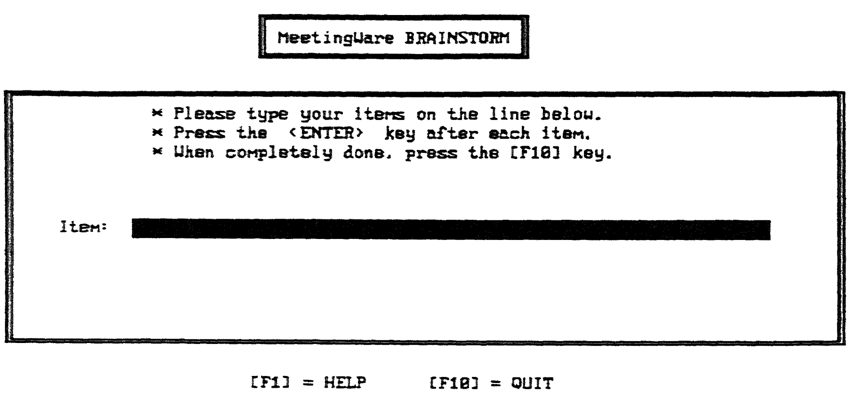



**Figure 10.4**
**MeetingWare Brainstorm Module**



discussed by Maier (1967) and Hoffman (1982). DISCUSS is designed to even out the amount of attention paid to ideas on the list so that all ideas get a fair hearing.

DISCUSS reads a list of items from an ASCII text file and then manages a timed discussion of the items using the main shared screen at the front of the room. The group sets the amount of time to consider each item at the beginning of the process (we recommend two minutes per item initially).

The group will then see the DISCUSS screen where the items are displayed, one at a time, along with a timer and some instructions (Figure 10.5). The group is instructed to determine whether each item is appropriate (belongs on the list), unique (has not already appeared on the list), and singular (does not contain multiple ideas). After considering these criteria, the chauffeur may enter an idea into a structured outline in the ORGANIZE module, which is often executed simultaneously with DISCUSS. After the items are inserted into the outline, the group may discuss the merits of the ideas. The chauffeur can interrupt the timer at any time to move on to a new idea, or the group can extend the discussion beyond the allotted time if they desire a more thorough analysis.

COMMENT reads a list of topics from a file and then opens a modified BRAINSTORM session, where each topic is displayed one at a time at the top of the shared screen at the front of the room (Figure 10.6). Participants can then type in their comments about the topic, and each comment will appear on a list on the front shared screen. The author remains anonymous. Participants can assign codes, which the software can use to group the comments by categories (e.g., a + for a strength or a − for a weakness). This allows participants to input comments in parallel, more rapidly than in an oral discussion where speakers must take turns. It also provides a written record of the comments.

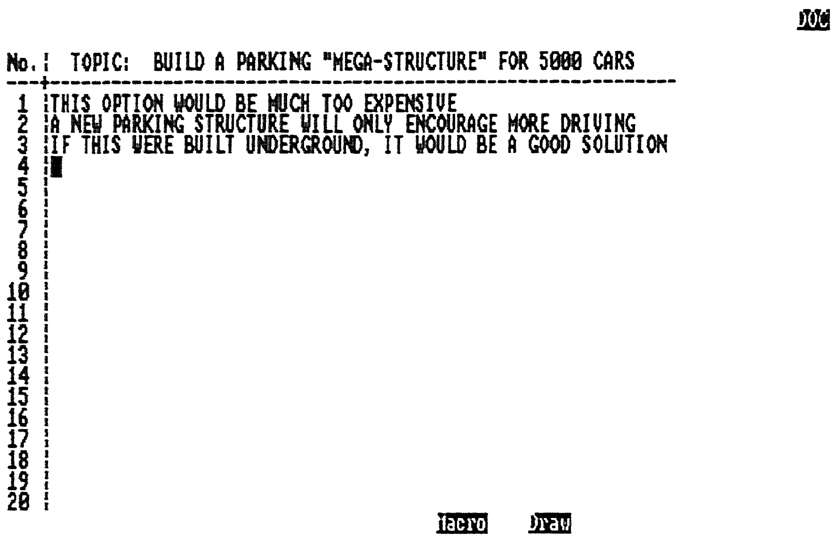
**Figure 10.5**
**MeetingWare Discuss Module**

```
        Is this item: * Appropriate?     What are its: * Strengths?
                      * Unique?                        * Weaknesses?
                      * Singular?

ITEM 1  GAS MILAGE IS CRITICAL DURING THIS PERIOD OF TIGHT BUDGETS

Time left:  2 Min  53 Sec     [F1]=Break     Remaining: 2 Items  6 Min
```

**Figure 10.6**
**MeetingWare Comment Module**




### List Organization

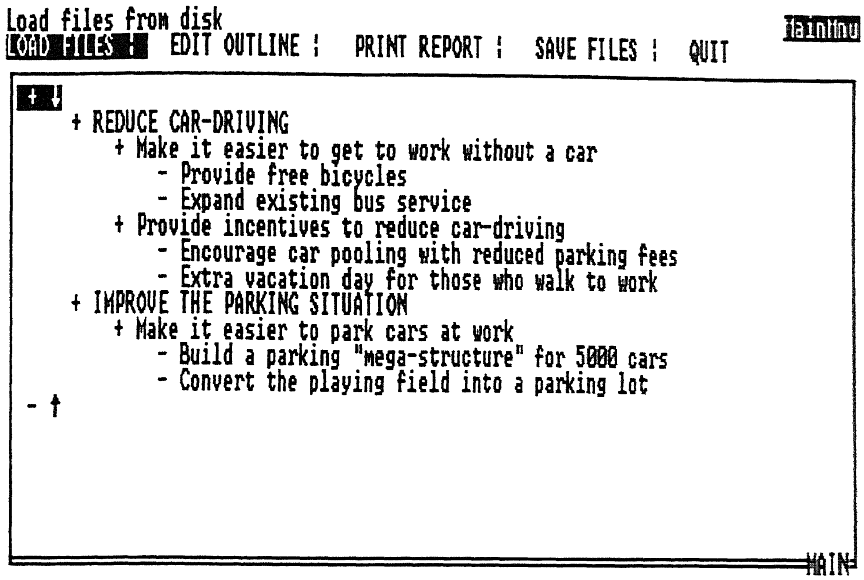
Two modules are generally concerned with list organization: LIST EDIT and ORGANIZE. LIST EDIT contains a minimum set of functions for modifying a list of ideas. The group can edit or delete existing ideas and can add new ideas to the list. This module is appropriate when dealing with a short, simple list in which all ideas are on the same level of analysis.

If the group needs to work with a more complex list of ideas where it is important to structure the list, the ORGANIZE module may be more appropriate. ORGANIZE builds outlines, which is a technique for organizing ideas that almost everyone knows how to use (see Figure 10.7 for a typical screen).

With ORGANIZE, groups can structure lists in at least three different ways: (1) they can group items together based on similarity; (2) they can place items at different levels of the outline to represent different levels of analysis; and (3) they can place items so as to represent temporal ordering or sequence. As they build the outline, it is displayed on the front screen, and ideas can be placed in the appropriate location in the outline following discussion by the group. This can help reduce conflict arising when group members approach a problem from differing points of view or levels of analysis (Gilbert 1978).

The group can easily change the outline by moving, copying, inserting, or deleting sections. Once an outline is completed, the group can decide to extract part or all of the outline, sort it, and then write it to a file. Thus, par-

**Figure 10.7**
**MeetingWare Organize Module**




ticipants can isolate any section or level of an outline for further processing by other MeetingWare modules.

When sufficient equipment is available (two PCs with video projection devices) it is often useful to combine the DISCUSS and ORGANIZE modules in what we call the *dual screen mode.* In this approach, one PC runs the DISCUSS module, which displays the list of ideas one at a time at the front of the room. A second PC simultaneously runs the ORGANIZE module, which displays the outline at the front of the room next to the DISCUSS display. As each item comes up for discussion, the chauffeur enters it into the outline as determined by the group.

### Item Evaluation

Groups can use several modules to evaluate items on a list: CROSS-IMPACT ANALYSIS, VOTE, RANK, RATE, and WEIGHTED FACTORS ANALYSIS. CROSS-IMPACT ANALYSIS can compare any two lists of items. For example, a group might want to compare solution alternatives to obstacles in order to indicate which solutions might help overcome which obstacles. Individual participants can indicate both the strength and direction of an impact by using a $-5$ to $+5$ scale. The software creates summary matrices that show either the sum of the groups' judgments or an average. The group can also view matrices showing the level of agreement regarding an interaction, by choosing to see the standard deviation or range displays.

All these matrices can be filtered to show only values in a desired range (e.g., all the high or low values). Graphs showing the specific ratings for a given interaction are available, which allows for an analysis of the evaluation without compromising the anonymity of participants. Three typical CROSS-IMPACT screens are shown in Figures 10.8, 10.9, and 10.10.

The VOTE, RANK, and RATE modules are somewhat similar. In VOTE, a participant casts a vote for a single preferred item. In RANK, each participant arranges the items in rank order. The RATE module allows the participants to indicate their preferences on a 1–10 scale. Each module provides a summary of the evaluation on the shared screen, showing total or mean values, and a graphic display of the distribution of votes, ranks, or ratings. A typical group summary screen is shown in Figure 10.11.

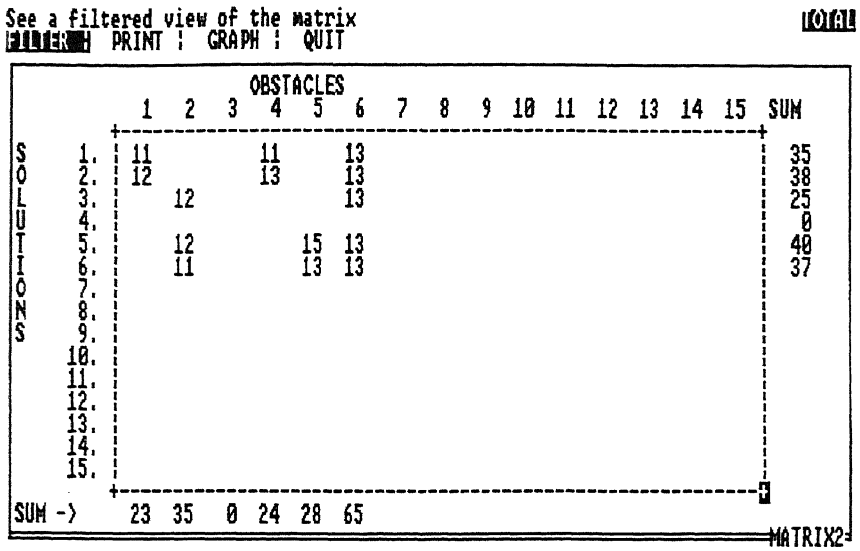
The WEIGHTED FACTORS ANALYSIS module is the most complex of the evaluation approaches. This multiattribute tool allows the group to evaluate up to ten alternatives at a time using up to fifteen criteria. The participants can individually assign weights to each criterion, and the system will calculate group weights by taking the mean value. Then each participant rates how well each alternative meets each criterion. The product of the weight and rating determines the score for a given alternative on a given criterion. The software sums these scores across all criteria for each alternative, and the alternative with the highest score is considered the best. The software integrates individual evaluations into a master matrix that summarizes the results, using the mean of the groups' individual scores. A typical

**Figure 10.8**
**MeetingWare Cross-Impact Module**

```
See a filtered view of the matrix                                     TOTAL
FILTER   PRINT | GRAPH | QUIT

                            OBSTACLES
                1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  SUM
              +-----------------------------------------------------------+
S       1.  | 11  -7  -8  11  -6  13                                      |  14
O       2.  | 12 -12  -6  13 -11  13                                      |   9
L       3.  |  8  12   8   7   6  13                                      |  54
U       4.  |  5  10  10   3  10 -11                                      |  27
T       5.  |-12  12  10  -9  15  13                                      |  29
I       6.  |-10  11   9 -11  13  13                                      |  25
O       7.  |                                                             |
N       8.  |                                                             |
S       9.  |                                                             |
       10.  |                                                             |
       11.  |                                                             |
       12.  |                                                             |
       13.  |                                                             |
       14.  |                                                             |
       15.  |                                                             |
              +-----------------------------------------------------------+
SUM ->        14  26  23  14  27  54
                                                                    MATRIX2
                                        Macro      Calc
```

**Figure 10.9**
**Cross-Impact Matrix Filtered for High Values**




| SOLUTIONS \ OBSTACLES | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 11 | | | 11 | | 13 | | | | | | | | | | 35 |
| 2. | 12 | | | 13 | | 13 | | | | | | | | | | 38 |
| 3. | | 12 | | | | 13 | | | | | | | | | | 25 |
| 4. | | | | | | | | | | | | | | | | 0 |
| 5. | | 12 | | | 15 | 13 | | | | | | | | | | 40 |
| 6. | | 11 | | | 13 | 13 | | | | | | | | | | 37 |
| 7. | | | | | | | | | | | | | | | | |
| 8. | | | | | | | | | | | | | | | | |
| 9. | | | | | | | | | | | | | | | | |
| 10. | | | | | | | | | | | | | | | | |
| 11. | | | | | | | | | | | | | | | | |
| 12. | | | | | | | | | | | | | | | | |
| 13. | | | | | | | | | | | | | | | | |
| 14. | | | | | | | | | | | | | | | | |
| 15. | | | | | | | | | | | | | | | | |
| SUM -> | 23 | 35 | 0 | 24 | 28 | 65 | | | | | | | | | | |

WEIGHTED FACTORS matrix screen is shown in Figure 10.12. Since this report contains such a wealth of detailed information, a set of graphics displays is available as an aid to analysis. One summary display shows the final weighted scores as a set of bar graphs, which makes it easy to see how each alternative performed (Figure 10.13).

A more detailed analysis is possible by displaying graphs showing how

**Figure 10.10**
**Graph of Cross-Impact Scores**

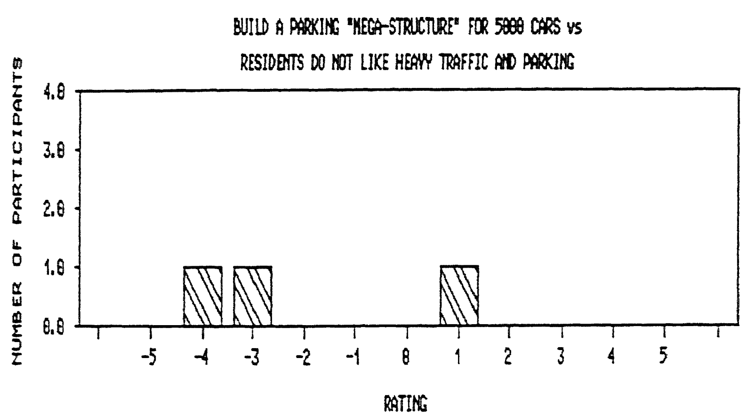


**Figure 10.11**
**MeetingWare Rate Summary Screen**

```
C [ENTER] to continue / Q [ENTER] to quit ---> _
```

| # | ITEM | AVERAGE RATING |
|---|---|---|
| 1. | EXPAND EXISTING BUS SERVICE | 9.00 |
| 2. | ENCOURAGE CAR POOLING WITH REDUCED PARKING FEES | 7.57 |
| 3. | EXTRA VACATION DAY FOR THOSE WHO WALK | 7.00 |
| 4. | PROVIDE FREE BICYCLES | 5.57 |
| 5. | CONVERT THE PLAYING FIELD INTO A PARKING LOT | 2.71 |
| 6. | BUILD A PARKING "MEGA-STRUCTURE" FOR 5000 CARS | 2.14 |

27-Aug-91
12:03 PM

REPORT

lacro Calc

**Figure 10.12**
**Weighted Factors Summary Matrix**

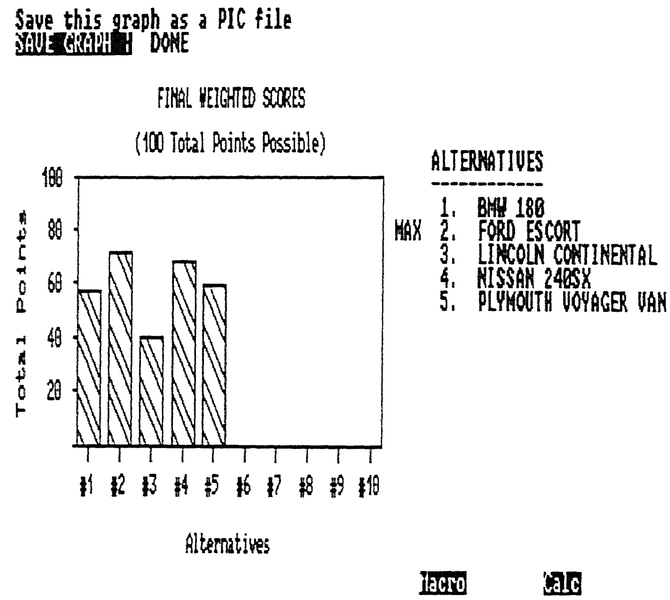
View Matrix at Right
---> <--- FILTER | GRAPH | PRINT | DONE

Current Filter:
MIN = 0.0 MAX = 10.0

| CRITERIA | Wts. | ALTERNATIVES 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 | 2.83 | 3.9 /10.9 | 8.3 /23.4 | 2.7 / 7.7 | 6.3 /17.8 | 7.0 /19.8 |
| 2 | 3.61 | 5.6 /20.1 | 8.0 /28.9 | 3.4 /12.4 | 6.3 /22.7 | 6.0 /21.7 |
| 3 | 2.29 | 8.1 /18.6 | 5.4 /12.4 | 4.7 /10.8 | 7.7 /17.6 | 5.1 /11.8 |
| C 4 | 1.27 | 6.1 / 7.8 | 5.1 / 6.5 | 7.7 / 9.8 | 8.1 /10.3 | 4.9 / 6.2 |
| R 5 | | / | / | / | / | / |
| I 6 | | / | / | / | / | / |
| T 7 | | / | / | / | / | / |
| E 8 | | / | / | / | / | / |
| R 9 | | / | / | / | / | / |
| I 10 | | / | / | / | / | / |
| A 11 | | / | / | / | / | / |
| 12 | | / | / | / | / | / |
| 13 | | / | / | / | / | / |
| 14 | | / | / | / | / | / |
| 15 | | / | / | / | / | / |
| Weighted Totals > | | 57.5 | 71.3 MAX | 40.7 | 68.5 | 59.4 |

lacro

**Figure 10.13**
**Weighted Factors Summary Graph**




each alternative scored on each criterion. An example for the first four criteria is shown in Figure 10.14. This can be truly useful in helping the group understand why an alternative did well or poorly in the final analysis. It is also possible to show tables summarizing the level of agreement on the item ratings, as measured by the standard deviation or range of the scores (Figure 10.15). When the software identifies an item with a high standard deviation, it can display a graph that shows the specific scores assigned by the group while still retaining individual anonymity. This makes it possible to identify areas of agreement and disagreement quickly, so that the group can focus on important issues.

The weighted factors analysis module includes another feature that can help a group understand their preference model: sensitivity analysis. It can often be useful to explore the impact of changes in the weights assigned to the criteria or the ratings assigned to the alternatives. This is especially true when there is no single alternative that scores well above all others or when there is considerable uncertainty about the appropriate weights or ratings. The criteria sensitivity analysis routine displays the criteria and their current weights and then allows the chauffeur to modify the weights and run the preference model again, calculating a new weighted factors matrix (Figure 10.16). Thus, the group can explore the effect of varying the criteria weights in an easy and efficient manner. Each time, the group can view the graphs and can print a report as a permanent record of the scenario. In a similar

**Figure 10.14**
**Alternatives Rated by Criteria**

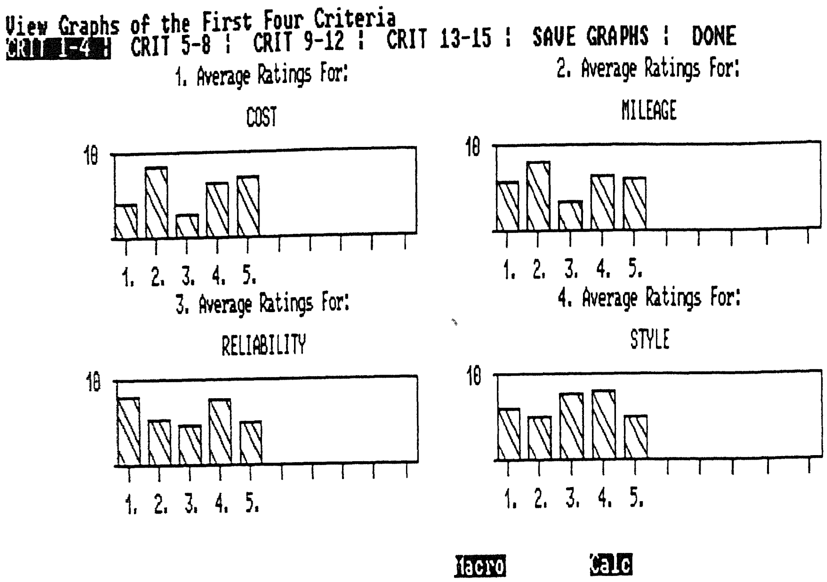



**Figure 10.15**
**Filtered Standard Deviation Scores**

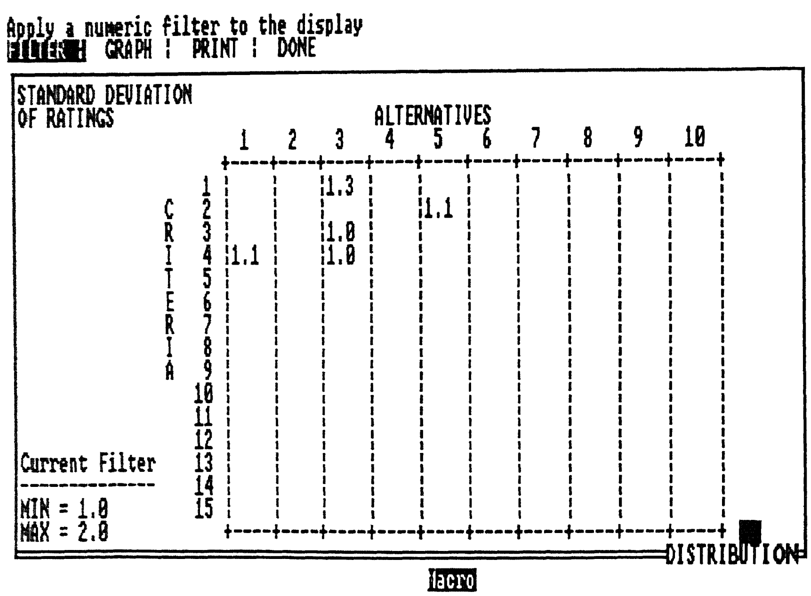


**Figure 10.16**
**Sensitivity Analysis Using Criteria**

```
Enter Criteria Number (99 = Done) --> _

                                 Current Cumulative
 #  Criteria                     Weight    Total
 ----------------------------------------------
 1. COST                          28.29    28.29    Points left -->
 2. MILEAGE                       36.14    64.43    to Allocate    -----
 3. RELIABILITY                   22.86    87.29
 4. STYLE                         12.71   100.00

                                                    Average weight
                                                    for 4 criteria
                                                    would be  -->  25
                                                                   -----

                                                             SENSITIVITY
                              Macro      Calc
```

manner, the group can modify the ratings for an alternative and see the impact on final weighted scores. When the sensitivity analysis is completed, the system can restore the original weights and ratings automatically.

### Information Sharing

MeetingWare provides two tools that support information sharing for the group. The first, VIEWER, allows the group to share information during a session through the shared display at the front of the room. This module will load any Symphony or Lotus 1-2-3 application and allow the group to view or manipulate the application. This could include a spreadsheet model, a database, a text document, or a graph.

The second tool, REPORTWRITER, allows the facilitator to work with history files created during one or more MeetingWare sessions and create a final summary report of the group's activities. It is essentially a word processor designed to work with MeetingWare data files.

### Session Management

Two tools help in managing MeetingWare sessions. SCRIPTWRITER supports the design, modification, and execution of meeting scripts (Figure 10.17). Basically, it allows the meeting facilitator to choose the modules she

or he desires for a meeting and to define the purpose of each tool and the file names that they will use to save the data. It makes it easy to insert, delete, edit, or move steps in a meeting script. It then makes a meeting semiautomatic by executing the script as defined by the facilitator. However, the script retains flexibility since it can be modified during a meeting, as group needs dictate.

The SESSION MANAGER module helps manage GDSS environments where there may be many clients and/or many facilitators using MeetingWare. It will help the facilitator install the correct data files for a session and back up the files at the end of the session. It reduces the possibility that files from different groups will become intermixed on the system, leading to confusion.

## BENEFITS OF MEETINGWARE

MeetingWare includes a variety of features that provide important benefits to decision-making groups. A summary of these benefits is given in Figure 10.18, organized by tool module. Let us consider these benefits.

### Anonymity

MeetingWare provides anonymity in three critical phases of decision making: idea generation, idea discussion, and idea evaluation. During idea gen-

**Figure 10.17**
**MeetingWare Script Writer**

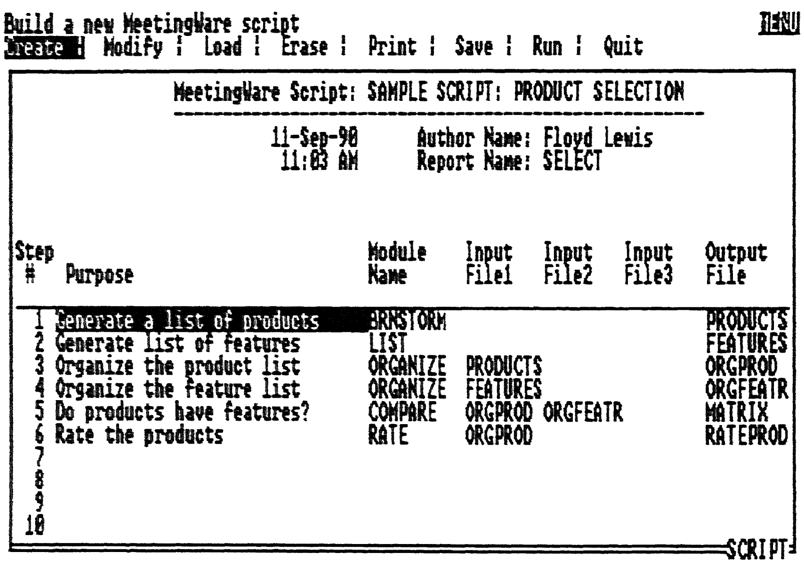


**Figure 10.18**
**Features and Benefits of MeetingWare**

| | LIST | BRAIN-STORM | DISCUSS | COMMENT | LIST EDIT | ORGANIZE | CROSS IMPACT | VOTE | RANK | RATE | WEIGHTED FACTORS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Anonymity | *** | *** | | *** | | | *** | *** | *** | *** | *** |
| Focused Discussions | | | *** | *** | *** | *** | | | | | |
| Parallel Input | *** | *** | | *** | | | *** | *** | *** | *** | *** |
| Report Generation | *** | *** | | *** | *** | *** | *** | *** | *** | *** | *** |
| Text Manipulation | *** | *** | | *** | *** | *** | | | | | |
| List Structuring | | | | *** | | *** | | | | | |
| Preference Analysis | | | | | | | *** | | *** | *** | *** |
| Rapid Computations | | | | | | | *** | *** | *** | *** | *** |
| Rapid Sorting | | | *** | *** | | *** | *** | *** | *** | *** | *** |
| Shared Public Display | | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| Personal Workstation | *** | *** | | *** | | | *** | *** | *** | *** | *** |

eration, this feature is intended to reduce conformity pressures and, thus, increase the likelihood that participants will contribute ideas in which they truly believe. It is also intended to increase the probability that participants will contribute creative or unusual ideas. Both the LIST and BRAINSTORM tools provide anonymity. It should be noted that nothing prevents a participant from revealing their authorship of an idea if they so desire, and such behavior has not been unusual. The GDSS chauffeur is trained to discourage participants from trying to guess authorship of others' ideas or from engaging in any behaviors designed to pressure others to reveal their authorship.

The COMMENT tool allows for anonymous written discussions. While this can be a very useful feature, we do not believe it should always replace the alternative approach, DISCUSS, which allows for face-to-face oral discussions. However, when there are valid reasons for anonymity, COMMENT will provide it.

During idea evaluation, anonymity is intended to protect participants' privacy so they feel free to express their true judgments concerning the worth of contending ideas. All the evaluation modules allow for an anonymous expression of individual judgments. While participants are also free to reveal their evaluations, this has rarely occurred. As in the idea generation phase, participants are discouraged from pressuring others to reveal their evaluations.

### Focused Discussions

Groups frequently experience problems staying focused on the task at hand; it is all too easy to wander off on tangential issues. In addition, when multiple ideas need discussing, groups frequently spend disproportionate amounts of time on the first few ideas discussed, while virtually ignoring ideas at the bottom of the list. Four tool modules help groups overcome these problems: DISCUSS, COMMENT, LIST EDIT, and ORGANIZE.

By presenting lists of ideas one at a time on a common screen, the DISCUSS and COMMENT modules focus attention on the current idea. DISCUSS helps to even out the time spent discussing each idea by using a timer. The focus around the common screen appears to make it easier for members to give up their personal ownership of an idea and seems to result in a sense of group ownership of these ideas. The LIST EDIT and ORGANIZE modules also tend to focus groups around the shared tasks of revising and structuring a list.

### Parallel Input

One of the limitations of verbal discussions for idea generation is the requirement that only one person talk at a time. Several MeetingWare tool

modules allow all participants to enter information simultaneously: this includes both of the idea generation tools, the COMMENT tool, and all the evaluation tools. This timesaving feature assumes that the system is running in a full network configuration. Recent GDSS field studies (Keleman, Garcia & Lewis 1989; Lewis & Keleman 1990) report that participants experienced gains in meeting efficiency.

### Report Generation

Groups frequently rely on a single member to keep track of actions and decisions in the group and to record them in the minutes. This approach can lead to problems of accuracy, completeness, timeliness, and potential bias. All the MeetingWare modules except DISCUSS can automatically produce reports summarizing group activities. Typical reports include lists, outlines, comparison matrixes, and evaluation results (numeric and graphic summaries). Unlike many meetings where members may wait days or weeks for minutes and meeting reports, MeetingWare reports are available immediately, without any significant delay.

### Text Manipulation

When groups use chalkboards and flipcharts, it is often difficult and messy to edit and manipulate text. Four MeetingWare tools allow participants easily to edit their ideas to correct mistakes or clarify meanings. While ideas are first being entered (in LIST, BRAINSTORM, or COMMENT), participants have access to a set of line editing commands to insert, delete, or modify text. In addition, when the whole group is considering lists of ideas (in LIST EDIT and ORGANIZE), they have access to a similar set of editing commands to make agreed-upon changes. The result is often a well-constructed list of clearly stated ideas, without messy corrections.

### List Structuring

There is another form of text manipulation that is even more difficult with chalkboards and flipcharts: organization or structuring of lists of ideas. If idea generation always resulted in ideas expressed at the same level of analysis, with a single topic focus, then list organization might not be necessary. This is seldom the case. Commonly, groups generate lists of ideas expressed at different levels of analysis and/or centered around different though related topics. It is often confusing to try to deal with these items on a single list, and it can be impossible to evaluate such a diverse list meaningfully.

MeetingWare provides a means to handle this problem through the ORGANIZE module. An outline can represent the structure of the ideas generated by the group. The manipulation of this outline is simple and

straightforward, compared to the manipulation of flipcharts or chalkboard diagrams. After a group successfully organizes a list, they can extract sections or levels of the outline for separate evaluation, thus avoiding a confounding of levels or topics.

When a group uses COMMENT along with ORGANIZE, they can merge the typed lists of comments with the original list of topics automatically. If they entered codes during the COMMENT session, the ideas will be grouped by their codes in the outline under the appropriate topic.

### Preference Analysis

For some evaluation methods, it may be useful for the group to review the pattern of individual judgments without being able to connect specific individuals with their evaluations (i.e., anonymity is preserved). This may help identify errors in evaluation (such as scale reversal) and/or areas of consensus and disagreement. The CROSS-IMPACT, RANK, RATE, WEIGHT, and WEIGHTED FACTORS modules provide a means for such analysis of preference patterns. The group will be able to review the ranks or ratings given to each item but will not know who assigned them. MeetingWare chauffeurs are instructed to look for certain patterns that may indicate a need for discussion. These modules allow the participants to modify their most recent set of evaluations following such a discussion.

CROSS-IMPACT and WEIGHTED FACTORS ANALYSIS include additional features for preference analysis. Both contain tables summarizing the standard deviation and range of the group's scores, as well as filters for quickly identifying areas of agreement and disagreement.

### Reduced Computational Overhead

Computers are well known for their ability to perform rapid mathematical calculations. MeetingWare takes advantage of this feature for the combination of individual preferences into group preferences. Although the mathematics involved are not especially complex, a large number of operations can be involved in such preference calculations, and manual methods can be slow, tedious, and error prone. Indeed, although methods such as weighted factors analysis are superior for groups coping with complex decisions, these techniques are often avoided because they are so difficult to use in a manual setting. The evaluation modules in MeetingWare reduce the manual computational overhead to zero and may result in a greater willingness to use more sophisticated decision making methods.

### Rapid Sorting

It is frequently convenient to work with lists that have been meaningfully sorted. A number of MeetingWare modules can sort lists, either alphabeti-

cally or by an evaluation value such as rank or rating. Although it is not impossible to sort material manually, the ease with which a computer sorts material makes it a more attractive option from a practical point of view.

## EXPERIENCES WITH MEETINGWARE APPLICATION

Several laboratory and field studies have been conducted with MeetingWare and its predecessor, FACILITATOR. The first laboratory study was carried out in 1982 and is described in detail elsewhere (Lewis 1987). This study found evidence that a GDSS can improve both the product of group problem solving (solution alternatives) and the group process itself (participation, creativity). It also found that the group members accepted the use of a GDSS.

After this initial study, the FACILITATOR software was completely rewritten, and another laboratory study was carried out in 1985. Evidence was found that this GDSS reduced conflict, brought order to the discussions, encouraged equality of participation, and did not reduce interpersonal support in the groups. The studies provided a great deal of useful information about GDSS design issues, many of which are discussed in Lewis and Keleman (1988). In 1986–1987 FACILITATOR was used to support a countywide group of twenty-two local public and not-for-profit organizations charged with coordinating economic planning efforts. As one part of a larger planning process, representatives from these organizations were placed into three groups that used a GDSS approach to consider objectives, obstacles and constraints, and action strategies. The process resulted in the first agreed-upon coherent framework for guiding economic development in the county. A postsession questionnaire indicated that participants felt the GDSS improved the efficiency, effectiveness, and overall productivity of the groups. They felt that there was far more equality of participation than in their experience with ordinary groups. All of the participants said they would like to use a GDSS again. (This study is described in greater detail in Lewis, Keleman & Garcia 1988.)

Following this field study, the FACILITATOR system was decomposed into a set of smaller modules, renamed MeetingWare. This system has been used in another field study over the last three years. A human resources division of a regional university decided to use a GDSS in support of its yearly planning efforts. Over the three-year period, there has been a noteworthy impact on the quality of the yearly plan. Goals are better articulated and more specific, with measurable outcomes. Constraints and resources are now clearly identified and associated with relevant goals. A greater number of action strategies have been identified for each goal. Through a questionnaire, participants have indicated they feel the GDSS improved the productivity, efficiency, and effectiveness of the group, and all participants said they would use a GDSS again and would recommend it to others. (A com-

plete description of this study can be found in Keleman, Garcia & Lewis 1989.)

A recent study using MeetingWare was carried out at Curtin University of Technology in Perth, Western Australia. Two aspects of GDSS use were studied: perceptions of professional facilitators concerning GDSS impacts and impacts of GDSS on the workloads of chauffeurs, facilitators, and group participants. An initial report regarding the first aspect can be found in Lewis and Whiteley (1992); the second is described in Pollock, Atkinson, and Lewis (1992).

## FUTURE PLANS

Like many other current software products, MeetingWare is being modified and improved in a continuous development cycle. In its current form, it includes somewhat more than the minimum set of modules necessary to be a useful GDSS. Over the next several years, we anticipate adding a number of new features to enhance its usefulness. For example, we are working on a version for Microsoft Windows. We are also exploring the possibility of opening the MeetingWare platform to others who may want to develop specialized modules to add to the library. Some of the specific modules we anticipate adding are discussed below.

### Additional Evaluation Tools

A number of techniques have been described for evaluation of group preferences that are more sophisticated than those currently provided by MeetingWare (Raiffa 1970; Sage 1977; Saaty 1986). It is likely that one or more of these will be added as tool modules in the next few years. A significant issue is whether these tools can be presented in such a manner that groups without technical backgrounds will be willing and able to use them.

### Graphics

Some concepts are best expressed visually, and some group participants are likely to "think visually" more than others. We would like to offer a graphics-oriented tool module in MeetingWare. Such a tool could be used to draw sketches, flowcharts, diagrams, and so on. This can be especially useful for exploring the organization and structure of problems. A formal technique for problem representation such as consensus mapping (Hart et al. 1985) might be a useful addition to a GDSS tool kit.

### Asynchronous Support

While our primary interest has been in face-to-face groups, we realize that on many occasions it is difficult and/or unnecessary to gather an entire

oup together at one time in one place. Several of the MeetingWare tools uld be modified to allow for asynchronous meetings. Primary candidates ight be the LIST tool and all the evaluation tools. Thus, participants could nerate and enter their ideas at their own convenience and then meet as a hole group for discussion and list organization. Finally, an evaluation iase could take place over a one- or two-day period as each member had ne to use the system to enter judgments. The entire group could meet ;ain to review evaluation results and revote if desired.

### Process Monitor

It may be useful for a group to have real-time assessments of participant elings about the group process. This could include issues such as need for eaks, relevance of current activities, levels of conflict, agenda setting, and on. A GDSS might include a simple pop-up polling mechanism to allow r these process checks. In some cases, a continuous graphic display might the best approach (e.g., a "conflict meter").

### Knowledge-Based GDSS Adviser

As more and more MeetingWare tools become available, it becomes more fficult to choose the appropriate tools and combine them in meaningful quences, especially for novices. We have developed a prototype of a iowledge-based system that gives advice to potential MeetingWare users. It lps to determine whether a GDSS approach appears appropriate for their uation, whether they have the necessary resources to proceed, and what ol modules they should consider. Ultimately, we anticipate expanding the pabilities of this system so that it can write complete MeetingWare scripts r GDSS users.

## JMMARY

MeetingWare is an example of a new class of software designed to support cision making in small face-to-face groups. It provides a set of modular ols that can be flexibly combined in various patterns to meet the unique eds of specific groups. Initial laboratory and field studies indicate that cision support systems such as MeetingWare can improve both the process id product of small group decision making. New capabilities planned for e near future should increase the effectiveness of this GDSS software.

## EFERENCES

ostrom, R. (1991). "Training people to facilitate electronic environments." Workshop on "Facilitation in Group Support Technologies," Twenty-fourth Annual Hawaii International Conference on Systems Science.

Chung, K., and M. Ferris. (1981). "An inquiry of the nominal group process." *Academy of Management Journal, 55,* 520–524.

Delbecq, A., A. Van de Ven, and D. Gustafson. (1975). *Group Techniques for Program Planning.* Glenview, IL: Scott-Foresman.

Dennis, A., J. George, L. Jessup, J. Nunamaker, and D. Vogel. (1988). "Information technology to support electronic meetings." *MIS Quarterly, 12*(4), 591–624.

Dennis, A., J. Nunamaker, and D. Vogel. (1990–1991). "A comparison of laboratory and field research in the study of electronic meeting systems." *Journal of Management Information Systems, 7*(3) (Winter), 107–135.

DeSanctis, G., and B. Gallupe. (1985). "Group decision support systems: A new frontier." *Data Base* (Winter), 3–10.

Diener, E. (1980). "Deindividuation: The absence of self-awareness and self-regulation in group members." In P. B. Paulus (ed.), *Psychology of Group Influence.* Hillsdale, N.J.: Erlbaum.

Easton, G., J. George, J. Nunamaker, and M. Pendergast. (1990). "Two different electronic meeting system tools." *Journal of Management Information Systems, 7*(1) (Summer), 85–100.

Ellis, C., G. Rein, and S. Jarvenpaa. (1989–1990). "Nick experimentation: Selected results concerning effectiveness of meeting support technology." *Journal of Management Information Systems, 6*(3) (Winter), 7-24.

Gallupe, B., G. DeSanctis, and G. Dickson. (1988). "Computer-based support for group problem-finding: An experimental investigation." *MIS Quarterly, 12,* 277–298.

Gilbert, T. (1978). *Human Competence.* New York: McGraw-Hill.

Greif, I. (ed.). (1988). *Computer-Supported Cooperative Work: A Book of Readings.* San Mateo: Morgan Kaufmann.

Grohowski, R., C. McGoff, D. Vogel, B. Martz, and J. Nunamaker. (1990). "Implementing electronic meeting systems at IBM: Lessons learned and success factors." *MIS Quarterly, 14*(4) (December), 369–383.

Hart, S., M. Boroush, G. Enk, and W. Hornick. (1985). "Managing complexity through consensus mapping: Technology for the structuring of group decisions." *Academy of Management Review, 10,* 587–600.

Hoffman, L. (1982). "Improving the problem-solving process in managerial groups." In *Improving Group Decision Making in Organizations.* Edited by R. Guzzo. New York: Academic Press.

Huber, G. (1984). "Issues in the design of group decision support systems." *MIS Quarterly, 8,* 195–204.

Janis, I. (1981). *Groupthink.* Boston: Houghton Mifflin.

Jessup, L., T. Connolly, and J. Galegher. (1990). "The Effects of Anonymity on GDSS Group Process with an Idea-Generating Task." *MIS Quarterly, 14*(3) (September), 313-321.

Keleman, K., J. Garcia, and L. F. Lewis. (1989). "Group decision support system (GDSS) demonstration project: University human resource planning." Paper presented at the Thirtieth Annual Meeting of the Western Academy of Management, San Francisco, March.

Latane, B., K. Williams, and S. Harkins. (1979). "Many hands make light the work: The causes and consequences of social loafing." *Journal of Personality and Social Psychology, 37,* 822-832.

Lewis, L. F. (1987). "A decision support system for face-to-face groups." *Journal of Information Science, 13,* 211–219.

Lewis, L. F., and K. Keleman. (1988). "Issues in group decision support system (GDSS) design." *Journal of Information Science, 14,* 347–354.

———. (1990). "Experiences with GDSS development: Lab and Field Studies." *Journal of Information Science, 16,* 195–205.

Lewis, L. F., K. Keleman, and J. Garcia. (Fall 1990). "The use of a GDSS tool in regional economic planning: A case study." *Information Resources Management Journal, 3*(4), 16–27.

Lewis, L. F., and A. Whiteley. (1992). "Initial perceptions of professional facilitators regarding GDS impacts: A study using the grounded-theory approach." Twenty-fifth Annual Hawaii International Conference on Systems Science.

McGoff, C., A. Hunt, D. Vogel, and J. Nunamaker. (1991). "The role of the facilitator in the IBM decision support center process." Workshop on "Facilitation in Group Support Technologies," Twenty-fourth Annual Hawaii International Conference on Systems Science.

Maier, N.R.F. (1967). "Assets and liabilities in group problem solving: The need for an integrative function." *Psychological Review, 74,* 239–249.

Maier, N.R.F., and L. Hoffman. (1960). "Quality of first and second solution in group problem solving." *Journal of Applied Psychology, 44,* 278–283.

Mintzberg, H. (1971). "Managerial work: Analysis from observation." *Management Science, 18B,* 97–110.

Nunamaker, J., L. Applegate, and B. Konsynski. (1987). "Facilitating group creativity: Experience with a group decision support system." *Journal of Management Information Systems, 3*(4), 5–19.

Nunamaker, J., D. Vogel, A. Heminger, B. Martz, R. Grohowski, and K. Kraemer. (1989). "Experiences at IBM with group support systems: A field study." *Decision Support Systems, 5*(2), 183–196.

Osborn, A. (1963). *Applied Imagination.* New York: Scribners.

Pollock, C., D. Atkinson, and L. F. Lewis. (1992). "A study of the effect of group decision support systems on the workload of participants, chauffeurs, and facilitators." Working paper. Perth, Western Australia: Curtin University of Technology.

Raiffa, H. (1970). *Decision Analysis.* Reading, Mass.: Addison-Wesley.

Saaty, T. (1986). "Axiomatic foundation of the analytic hierarchy process." *Management Science, 23,* 841–855.

Sage, A. P. (1977). *Methodology for Large Scale Systems.* New York: McGraw-Hill.

Sanders, G., R. Cerveny, and C. Wang. (1991). "A descriptive framework for research in group decision conference support systems." *Proceedings of the Twenty-fourth Annual Hawaii International Conference on Systems Science, 3,* 48–52.

Straub, D., and R. Beauclair. (1988). "Current and future uses of the group decision support system technology: Report on a recent empirical study." *Journal of Management Information Systems, 5*(1), 101–116.

Tan, B., K. Wei, and K. Raman. (1991). "Effects of support and task type on group decision outcome: A study using SAMM." *Proceedings of the Twenty-fourth Annual Hawaii International Conference on Systems Science, 3,* 537–546.

Van de Ven, A. (1973). "An applied experimental test of alternative decision making

processes." Kent, Ohio: Kent State University.

Venkatesh, M., and B. Wynne. (1991). "Effects of problem formulation and process structures on performance and perceptions on a GDSS environment: An experiment." *Proceedings of the Twenty-fourth Annual Hawaii International Conference on Systems Science, 3,* 564–572.

Vogel, D., J. Nunamaker, W. Martz, R. Grohowski, and C. McGoff. (1989-1990). "Electronic meeting system experience at IBM." *Journal of Management Information Systems, 6*(3) (Winter), 25–43.

Watson, R., G. DeSanctis, and M. Poole. (1988). "Using a GDSS to facilitate group consensus: Some intended and unintended consequences." *MIS Quarterly, 12,* 463–480.

11

# Utilization of Decision-Aiding Software in the U.S. Government

Fred Wood

Advances in information technology are fueling a revolution in computer modeling, both inside and outside government. The 1980s and early 1990s have been characterized by the expansion of computer modeling, via low-cost microcomputers and user-friendly software, literally into the office of the individual scientist, engineer, analyst, or manager, and, simultaneously, via supercomputers, to the new limits of modeling complexity demanded in the scientific, energy, space, climate, and defense sectors. The span and diversity of computer modeling activities in the federal government have never been greater. About 60 percent of federal agency units responding to an Office of Technology Assessment (OTA) survey reported at least some use of computer modeling, with the number of applications ranging up to two thousand per agency component.

The use of computer-based decision analytic techniques has also increased dramatically. Such techniques typically include computer software that can help decision makers or staff analyze a specific problem, possible decision options, and the likely or possible consequences. About 90 percent of federal agency units report use of spreadsheet software, about one-half use quantitative decision techniques (e.g., linear programming), about one-fourth use forecasting and qualitative techniques (e.g., decision trees), and a handful use decision conferences and computer conferencing.

Overall, executive branch officials responding to the OTA survey believe these techniques to be very useful, even essential, to agency decision making. However, few can document this claim, other than by citing examples, because there has been little research on the impact of decision support techniques on agency decision making. The limited research that is available, primarily by academics on model implementation, suggests that models

(and, by extension, other decision analytic techniques) can and do have a significant impact on agency decision making. Modeling may become a significant element in the process of negotiation over assumptions and options that is an integral part of agency (and, in general, political) decision making. However, models can be wrong, and models can be misused.

Several possible actions could help improve sharing of expertise and learning; facilitate public and congressional access where appropriate; enhance congressional and public understanding of the strengths and limitations, uses and abuses of modeling; and improve the government's return on a significant investment:

- Establishing guidelines or standards for model documentation, verification, and validation.
- Establishing directories of major modeling applications.
- Clarifying procedures on public access to modeling details.
- Conducting further research on the impact of computer modeling and decision support on agency decision making.
- Conducting basic and applied research on modeling and decision support methodologies.
- Conducting further testing and development of the decision conference technique.
- Bringing computer modeling and decision support clearly within the scope of information resources management.

After a review of the entire range of known applications of information technology in the federal government, computer-based modeling and decision support stood out as application areas about which little concrete information was available. There was no current, reliable source of information on federal government use of computer-based modeling and decision support. In order to develop a sound basis for understanding trends and issues relevant to computer modeling, this topic was included in an OTA survey sent to all thirteen cabinet departments and twenty independent agencies.

For purposes of this survey, computer modeling included the entire range of mathematical models used to support agency activities and programs—from small models run on microcomputers in individual offices to large, complex models run on supercomputers. A model is an abstraction, analog, image, or representation of some aspect of current (or future) reality relevant, in this case, to the missions and programs of federal agencies. All but the very simplest mathematical models are now routinely programmed as sets of equations and run on computers. Thus, most models are computer-based models (computer models, for short). Computer models can be used for a variety of purposes, from conducting scientific research in aeronautics or climate, to engineering the design of a new highway bridge, to estimating

future numbers of school-age children, to analyzing the fiscal impacts of alternative Medicare reimbursement policies. Computer models can be and are used to support agency decisions but have many other purposes as well.

Consideration of computer-based decision support included several types of analytical techniques (along with the necessary computer software, hardware, data sets, graphic displays, and the like) used to support or assist decision makers. The categories of computer-assisted analytical techniques used in the OTA survey and in this chapter are:

- Spreadsheet computer software.
- Forecasting techniques (e.g., regression analysis, Delphi survey).
- Quantitative decision analytic techniques (e.g., linear programming, queuing analysis, systems analysis, critical path analysis).
- Quantitative decision analytic techniques with judgmental input (e.g., decision trees, subjective probability, multiattribute utility).
- Decision conference techniques (e.g., interactive use of computer-assisted analytical techniques by decision makers in a group situation).
- Electronic voting techniques (e.g., consensor, computer polling).
- Computer conferencing for decision analysis.
- Other (e.g., expert systems).

Most of these techniques also involve the use of models. For example, an analysis of the relationship between rainfall, temperature, and crop yield might use a computer-based multiple regression model to understand the performance of different varieties of crops under various climatic conditions or to help an agricultural extension agent or the Agency for International Development agricultural employee select specific varieties to recommend for spring planting.

This chapter presents OTA's findings on key trends and issues relevant to computer modeling and decision support.

## KEY TRENDS

### Information Technology Fueling Modeling Revolution

Several key technological developments have profoundly changed the conduct of analytical, forecasting, and research activities that utilize modeling. The first is the microcomputer revolution. From almost no microcomputers twelve years ago, federal agencies now have, collectively, more than 500,000. Access to computer power truly has been decentralized, both in terms of actual desktop computer capability and the use of microcomputers as access points to larger mainframe computer resources. This phenomenon parallels that found in the research and business communities outside government.

A second key trend is the large increase in user-friendly computer software, especially software suitable for microcomputers. This includes a wide range of spreadsheet, modeling, and decision analytic software that permits many small-scale, relatively simple decision analytic and modeling applications.

A third key technological trend is at the high end of computer power—the supercomputer. Supercomputers are extending the limits of modeling complexity, from aerodynamics to climate. In the United States, supercomputers have been installed at, for example, the Lawrence Livermore Laboratory (Department of Energy, DOE) for magnetic fusion research and the Ames Research Center (National Aeronautics and Space Administration, NASA) for numerical aerodynamics modeling. Both NASA and DOE officials have found that supercomputers are essential to their modeling activities.

Use of supercomputers is not limited to government agencies. For example, with National Science Foundation (NSF) funding, additional supercomputer centers have been established at several universities. At the University of Illinois, illustrative applications range from high-energy physics (e.g., simulation of a particle accelerator to test theories about elementary particles), to chemistry (e.g., simulation of molecular behavior), to civil engineering (e.g., modeling of transportation systems in the Chicago area), to physiology and biophysics (e.g., modeling of electrical activity of nerve and muscle cells).

The earliest computer modeling dates back to the 1950s when first-generation computers were used, for example, to run simple numerical models for weather prediction. Until around 1970, federal government modeling was concentrated in the scientific, energy, space, and defense sectors—sectors with the greatest computational needs and the resources to pay for the expensive but necessary computer power. During the 1970s, however, the widespread availability of relatively cheap computers contributed to the expansion of computer modeling activities to areas such as air pollution, water resources, solid waste management, urban development, and transportation. The 1980s and early 1990s have been characterized by the expansion of computer modeling, via low-cost microcomputers, literally into the office of the individual scientist, engineer, analyst, or manager and simultaneously via supercomputers, to the new limits of modeling complexity demanded in, for example, the energy and climate sectors.[1] The results of OTA's survey indicate that the span and diversity of computer modeling activities in the federal government have never been greater.

Weather and climate modeling is a good illustration of how computer modeling in general has essentially developed in parallel with advances in computer power. The record shows that the complexity of weather and climate models quickly expands to push the limits of the computational power and capacity of each successive generation of computer technology.[2]

### Continuing Heavy Federal Use of Computer Modeling

Federal agency use of computer modeling is substantial. Almost 60 percent of 141 agency components responding to the OTA survey reported some use of computer modeling to support agency activities and programs, and this excludes use of decision analytic techniques such as spreadsheet software. (The OTA survey was limited to the federal executive branch. Other OTA research reviewed use of computer modeling by congress[3] and state legislatures.[4])

For agencies that could estimate the total number of modeling applications, the number ranged up to two thousand per agency component. Among the heaviest reported computer model users are the Economic Research Services (Department of Agriculture), Office of Program Analysis and Evaluation (Department of Defense, DOD), U.S. Geological Survey (Department of the Interior), Federal Highway Administration (Department of Transportation, DOT), and the Nuclear Regulatory Commission (NRC).

OTA asked agency components to list the ten heaviest areas of modeling application. The results demonstrated the wide diversity in the purposes for which computer modeling is used by federal agencies. Examples from seven selected agencies are shown in Table 11.1.

Although the results of the OTA survey are not adequate to make a precise estimate of the number of modeling applications, it is clear that the total is far higher than previously thought. A 1982 General Accounting Office (GAO) survey identified 357 models used in the agency policymaking process, based on responses from twelve of the thirteen cabinet departments and eighteen independent agencies.[5] The GAO survey very likely underreported the total number of policy-relevant models as of that time (1982), and the number has probably increased since then. While a precise estimate is neither possible nor necessary, the ballpark minimum would appear to be in the thousands for policy models and tens of thousands for all types of computer models used by federal agencies. The numbers could be much higher, especially if spreadsheet-type models are included.

### Rapidly Increasing Federal Use of Computer-Based Decision Support and Analysis

Computer-based decision analysis dates back to the 1960s for its theoretical roots (e.g., as developed by Howard Raiffa of Harvard University)[6] and to the 1970s for its practical development and early application, primarily in the military and business sectors. Early federal government sponsors of research and development (R&D) on decision analysis included the Defense Advanced Research Projects Agency and the Office of Naval Research. The

**Table 11.1**
**Federal Agency Modeling Applications**

*Economic Research Service (Department of Agriculture)*
An estimated 2,250 computer modeling applications, including:
- analysis of farm program alternatives
- analysis of world food supply, capacity, and response
- analysis of conservation alternatives
- trade policy analysis
- forecasting of commodity supply and demand

*Forest Service (Department of Agriculture)*
An estimated 100 applications, including:
- timber resource allocation model
- integrated pest impact assessment system
- forest growth and yield analysis
- fire management and planning model
- engineering design models for roads, structures, and buildings

*Office of Secretary of Defense (Office of Program Analysis and Evaluation)*
An estimated 1,250 applications, including:
- impact of defense spending on U.S. economy
- strategic defense initiative effectiveness studies
- military force mobility modeling
- impact of procurement schedule changes on acquisition costs
- impact of second-source/competitive procurement on acquisition costs

*Joint Chiefs of Staff (Department of Defense)*
A large number of applications, including:
- strategic nuclear war plans analysis
- non-strategic nuclear force mix analysis
- military force posture analysis
- improving crisis war planning processes
- nuclear damage assessment

*Bureau of Indian Affairs (Department of the Interior)*
An estimated 15 applications, including:
- road and bridge design
- forest and range fire risk analysis
- rangeland usage and conditions analysis
- rangeland market appraisal
- oil and gas lease management and planning

*Office of Assistant Secretary for Program Evaluation (Department of Health and Human Services)*
A small number of applications, including:
- revenue impact analyses of, for example, including social security and welfare benefits in taxable income, providing additional tax exemptions for children in the first year after birth, and replacing Federal income tax credits for the elderly with higher deductions.
- estimates of participation rates for Aid for Dependent Children (AFDC) recipients in the Food Stamp Program.
- estimates of the Deficit Reduction Act impact on AFDC, Food Stamp, and Supplemental Security Income beneficiaries.

*Federal Emergency Management Agency*
An estimated 100 applications, including:
- mobilization for nuclear and general war
- earthquake damage and economic impact estimates
- residual capacity of U.S. economy after nuclear war
- strategic stockpile policy development
- flood damage analysis

*Source:* Office of Technology Assessment Federal Agency Data Request.

early decision analytic tools were implemented with paper and pencil, slide rule, and/or calculator.

Since decision analysis techniques may involve many options (e.g., numerical probabilities based on empirical evidence and/or quantified judgments of uncertain future events), the number of calculations per run can be large, and the typical application involves many runs with changing options and values. Thus, decision analysis is a natural match with electronic computer capability. Therefore, almost all decision analytic techniques are significantly, if not entirely, run on computers, at least for the computational aspects. Many decision analysis software packages are now available off the shelf for use on microcomputers, and the software and the hardware, together with relevant databases, are frequently known as decision support systems.

The results of the OTA survey provided a good profile of agency use of decision analytic techniques—the first complete profile known to exist. The results are likely to understate the full extent of use, given the highly decentralized nature of decision support. Nonetheless, the results are generally consistent with the perceptions of informed observers, especially with respect to the relative differences in levels of use for the various techniques.

The results are summarized in Table 11.2. Spreadsheet software is used by almost all (88 percent) of the agency components responding, and half of the remaining agency components (eight of sixteen) are planning to use spreadsheet software. Almost half (47 percent) of agency components report the use of quantitative decision analytic techniques, with another thirteen agency components planning to use such techniques. About one-fifth (22 percent) of agency components report the use of quantitative decision analytic techniques with judgmental input, and about one-fifteenth report the use of decision conference techniques. Nine agency components report the use of decision conferences, and another seven components indicate that they are planning to do so. About one-twentieth report the use of computer conferencing for decision support, and two agency components indicate the use of electronic voting techniques. Also, three components report the planned use of expert systems or artificial intelligence for decision support.

The use of spreadsheet software is spread throughout all agencies, and the use of quantitative techniques is fairly widespread in, for example, the Departments of Agriculture, Commerce, Defense, Interior, Transportation, and Treasury, and about two-thirds (twelve of nineteen) of the independent agencies surveyed. However, DOD is the only agency with more than half of agency components reporting use of quantitative decision analytic techniques with qualitative input (e.g., decision trees, multiattribute utility). DOD is the only agency reporting significant use of decision conferences (about one-third of DOD components reporting), although there was scattered, infrequent use reported in Agriculture, Interior, and Transportation.

With respect to use of quantitative decision analytic techniques, the Inter-

**Table 11.2**

**Federal Agency Current and Planned Use of Computer-Assisted Decision Analytic Techniques**

| Technique | Current use[a] Yes No. | Yes % | No No. | No % | Total No. | Planned use[b] No. |
|---|---|---|---|---|---|---|
| Spreadsheet software (e.g., Lotus 1-2-3, VisiCalc) | 121 | 88.3 | 16 | 11.7 | 137 | 8 |
| Quantitative decision analytic techniques (e.g., linear programming, queuing analysis, systems analysis, critical path analysis) | 64 | 47.4 | 71 | 52.6 | 135 | 9 |
| Forecasting techniques (e.g.. Delphi, regression analysis) | 33 | 24.6 | 101 | 75.4 | 134 | 13 |
| Quantitative decision analytic techniques with judgmental input (e.g., decision trees, subjective probability, multi-attribute utility) | 29 | 22.1 | 102 | 77.9 | 131 | 10 |
| Decision conference techniques (e.g., interactive use of computer assisted analytical techniques by decisionmakers in group situation) | 9 | 6.8 | 124 | 93.2 | 133 | 7 |
| Computer-conferencing for decision analysis | 6 | 4.6 | 124 | 95.4 | 130 | 4 |
| Electronic voting techniques (e.g.. consensor) | 2 | 1.5 | 132 | 98.5 | 134 | 1 |
| Other: Expert Systems, artificial intelligence | | | | | | 3 |

[a] Agency components reporting current use.

[b] Agency components reporting planning use of techniques not currently used.

*Source:* Office of Technology Assessment, based on results of Federal Agency Data Request.

national Economic Policy (IEP) Group of the International Trade Administration (Department of Commerce) is illustrative. This agency component combines the use of decision analytic techniques, models, and databases to "help improve decisionmaking" and "to enhance IEP's ability to provide policymakers and U.S. business with comprehensive information on trade and investment matters generally." As one other agency example, the Drug Enforcement Administration (DEA) (Department of Justice) is planning to use quantitative decision techniques to optimize allocation of agency resources (agents, monies for purchase of information and evidence, etc.) in terms of productivity as measured, for example, by the number of repeat offender arrests, volume and value of drug interdictions, and reductions in drug availability. Also, DEA plans to use quantitative techniques with judgmental input and artificial intelligence techniques for investigative and intelligence purposes.

Other examples of the use of decision analytic techniques, especially those combining quantitative and qualitative (judgmental) methodologies, include:

- DOD use of multiattribute utility analysis to aid in the evaluation and acquisition of major military systems such as the advanced scout helicopter, light armored vehicle, mobile protective weapons system, and single channel ground and airborne radio system.
- Defense Nuclear Agency use of multiattribute utility and cost-effectiveness analysis to aid in R&D budgeting.
- Department of the Air Force use of decision analytic techniques to aid in planning and targeting air strikes against enemy air bases and in developing command, control, and communication countermeasures.
- NRC use of decision analysis to aid in the evaluation of proposed new regulatory requirements and safeguard designs.
- DOE use of decision analysis to aid in implementation of the Nuclear Waste Policy Act of 1982 and the siting of repositories for high-level nuclear waste.
- National Security Council use of decision analysis in evaluating alternative strategies for the Middle East.
- President's Council on International Economic Policy use of decision analysis in evaluating alternative export control policies for computer technology.

## KEY OPPORTUNITIES FOR ACTION

### Guidelines or Standards for Model Evaluation

Efforts to manage computer modeling and to establish some minimum level of standards have always lagged behind the actual level of applications by many years. In the 1970s, as computer modeling applications proliferated throughout the federal government, the National Bureau of Standards

(NBS) (now the National Institute of Standards and Technology), Energy Information Administration (EIA), and the GAO took the lead in attempting to bring some coordination and coherence to civilian modeling activities. The Joint Chiefs of Staff (JCS) did similarly for defense modeling.

GAO issued reports in 1976, 1978, and 1979, and NBS issued reports in 1979 and 1981 (with EIA support).[7] A central theme in all of these reports was the need to develop a common framework for model evaluation or assessment. Many suggestions were made, but none was adopted on a government-wide basis. A very few individual agencies, such as EIA, eventually adopted some variant of a model evaluation procedure.

Given the extensive use of computer modeling by federal agencies, the level of formal model documentation, verification, and validation appears to be deficient. Clearly, computer models are judged to be important by many federal agencies and are used for purposes ranging from research to decision support. However, the research on computer modeling makes two things abundantly clear: models can be wrong, and models can be misused.[8] For these reasons alone, minimum modeling guidelines or standards appear to be needed. In addition, such guidelines presumably would make it easier to strengthen the federal modeling expertise and perhaps achieve a higher return on what must be a substantial federal investment. (OTA did not develop data on the costs of modeling, and most agencies are unable to estimate such costs readily.)

Some agencies (e.g., NBS, EIA, JCS) have made a concerted effort to develop and/or apply modeling guidelines. A lead role could be assigned to one of these agencies, perhaps NBS, or to one civilian and one military agency (e.g., NBS and JCS), for developing and promulgating a set of modeling guidelines. Much of the groundwork has already been done, and development of guidelines should be straightforward.[9] The lead agency presumably would involve all major modeling agencies in the guidelines development process. Guidelines for the major, expensive, complex computer models would logically be more complete and extensive than guidelines for small, simple, inexpensive desktop models. Computer modeling could be brought clearly within the purview of the information resources management concept, through appropriate amendments to the Paperwork Reduction Act if necessary.

### Directory of Modeling Applications

Prior studies of computer modeling in the federal government have generally concluded that directories of modeling applications would be helpful, at least for the major models. This possibility was reiterated in a 1982 OTA study on water resources models.[10] Given the extremely large number of applications, a comprehensive directory would appear to be costly and difficult to prepare, and many of the applications may not warrant the effort.

However, there is a stronger argument for a comprehensive directory of selected major models and for an index or pointer system to a larger number of other significant models and modelers, perhaps indexed by subject matter and type of model. These actions would be intended to help reduce possible excessive overlap and duplication, encourage exchange of modeling information among modelers, and facilitate a greater degree of public knowledge of and access to federal modeling. Some argue that modelers in any given area already know or can learn what they need to know about relevant modeling activities without the help of modeling directories. But given the number and diversity of modeling applications, this could be difficult.

Of eighty-two agency components that reported use of computer models, sixteen or about one-fifth indicated the existence of a modeling directory. Those agencies are:

Department of Agriculture: Economic Research Service and Forest Service.

Department of Defense: Joint Chiefs of Staff and Defense Contract Audit Agency.

Department of Energy: Energy Information Administration.

Department of the Interior: Minerals Management Service, U.S. Geological Survey, and Office of Surface Mining Reclamation and Enforcement.

Department of Justice: Justice Management Division.

Department of Labor: Bureau of Labor Statistics.

Department of Transportation: National Highway Traffic Safety Administration (NHTSA), Federal Highway Administration, and Federal Aviation Administration.

Nuclear Regulatory Commission.

Arms Control and Disarmament Agency.

Federal Emergency Management Agency.

Most of these directories are reported to be in paper format, although the Forest Service and NHTSA indicate that their directories are in an on-line electronic format. Also, the EIA model directory is in both computerized and printed formats.

In addition, some of these agency components report that they also have a central reference point—usually a designated person—with current information about modeling applications. Several other agency components that do not have a directory do claim to have a contact person. Among the latter agencies are the Defense Advanced Research Projects Agency, Defense Communications Agency, DOE agency wide (National Energy Software Center—a full clearinghouse operation, not just a person), Employment Standards Administration (Labor), Urban Mass Transit Administration (DOT), and Comptroller of the Currency (Treasury).

In total, a little more than one-third (thirty-one of eighty-two) of the agency components that use computer modeling report having a model di-

rectory and/or a designated contact person or, rarely, an actual clearinghouse. This one-third includes many of the agency components that appear to be among those with the heaviest modeling activity. These figures do not include model directories or clearinghouses that include federal agency models but are maintained by nonfederal entities (e.g., universities, professional associations, and private information companies).

With respect to decision analytic support, only five agencies reported a directory or clearinghouse of such applications. The decentralized and small-scale nature of most decision analytic applications probably makes a directory to these techniques unrealistic. However, for major modeling applications—such as the major energy, agriculture, water, transportation, and climate models—a directory appears to make sense. Such a directory or family of directories should be useful to all parties concerned—Congress, the public, agency modelers, researchers, and the like. Several prototypes exist. The directories would logically be computerized, to facilitate easy updating, and could be available in on-line electronic format as well as in paper and microform. A common table of contents would be helpful and presumably would be consistent with whatever modeling guidelines may be developed. The directories could be organized by, at a minimum, agency, subject area, and type of modeling application (e.g., scientific research decision support, program implementation) to facilitate easy reference.

A lead agency could be designated, perhaps the NBS, to study the options and develop a feasible directory design. The modeling directories and contact persons reported to OTA by the agencies should provide a good base from which to start.

### Clarified Procedures on Public Access to Modeling Details

Only about one-tenth of agency components using computer modeling have formal procedures or policies (beyond the Freedom of Information Act) on the availability of modeling details (e.g., structure, assumptions, input data) to the public and Congress, and there is wide variability among the procedures and policies that do exist. The overall results indicate that most agencies have not given much attention to questions of public and congressional access to model details. Some agencies cite the Freedom of Information Act as the guiding policy; others state that modeling details would probably be provided if sought by Congress. The following agencies indicated the existence of procedures or policies on the availability of model details to the public and/or Congress:

- Economic Research Service (ERS) (Agriculture).
- Bureau of the Census (Commerce).
- Joint Chiefs of Staff (DOD).
- Energy Information Administration (DOE).

- U.S. Geological Survey (Interior).
- Bureau of Labor Statistics (BLS) (Labor).
- Urban Mass Transportation Administration (Transportation).
- Federal Aviation Administration (Details).
- Nuclear Regulatory Commission.

Most of the major federal statistical agencies are included in this list because they use models in developing statistical trends and forecasts and because there is a highly visible public demand for their information products. Thus, there is a strong felt need to develop explicit access policies.

Even among the few agencies that have explicit policies, however, there is considerable variability in the level of public documentation that is routinely made available. This does not appear to reflect necessarily an agency judgment to withhold certain kinds of modeling information but appears to be more a reflection of the particular approach selected for model documentation. Examples from three agencies are presented in Table 11.3.

The EIA public documentation of major models is one of the most extensive of all agencies responding to the OTA survey. This is partly attributable to the high visibility of energy modeling, periodic concerns raised about the quality of EIA energy models and projections, and congressional and statutory requirements. For example, EIA has a statutory mandate to ensure "that adequate documentation for all statistical and forecast reports prepared . . . is made available to the public at the time of publication of such reports."[11] Since many such EIA reports are based on computer models, the models themselves are required to be documented. EIA has issued two orders that specify the format and public availability of model documentation.[12] In addition, in part in response to congressional criticism and outside audits and evaluations, it appears EIA has made significant progress in documenting the thirty-three major computer models currently in use.[13] EIA has made extensive use of model evaluations conducted by outside groups, as well as internal reviews.

The EIA and JCS model documentation provides considerably more information than the ERS format, since the latter is really a pointer system to help interested parties obtain more detailed information if desired. However, ERS also publishes reports on some of the major models. For example, a report on the ERS World Grain-Oil-Seeds-Livestock Model is sixty-four pages and includes a narrative description, illustrations of model equations and linkages, and values of key model parameters.[14] This report is backed up by an even longer technical report, also prepared by ERS staff. This suggests that even if modeling information available through directories or other public access mechanisms is limited, more detailed information may be available through technical reports prepared by agency (and/or consultant) staff and also by articles in the published literature. Even the EIA's detailed

**Table 11.3**
**Illustrative Agency Formats for Model Documentation**

*Economic Research Service (Department of Agriculture)*[a]
- Model name
- Responsible person(s)
- Model description
- Model applications
- Operating and updating costs

*Joint Chiefs of Staff (Department of Defense)*[b]
- Model title
- Model type
- Proponent (who maintains model)
- Developer
- Purpose
- General description
- Date implemented
- Input
- Output
- Model limitations
- Hardware
- Software
- Time requirements
- Security classification
- Frequency of use
- Users
- Point of contact
- Miscellaneous
- Keyword listing

*Energy Information Administration (Department of Energy)*[c]
- Model name
- Acronym
- Abstract
- Status
- Part of another model
- Sponsoring agency, office, division, branch
- Model contact
- Documentation
- Archive tape(s) and installation manual(s)
- Reviews conducted (of model)
- Purpose
- Energy system described by model
- Coverage (e.g., geographic, time unit/frequency)
- Special features
- Modeling features
  —Model structure
  —Modeling technique
  —Model interfaces
  —Input data
  —Date sources
  —Output data
- Computing environment
  —Language used
  —Core memory requirements
  —Estimated cost to run
  —Special features
- Status of evaluation efforts
- Date of last model update

[a] See U.S. Department of Agriculture, Economics and Statistics Service, *Agricultural and Other Economic Models of the Economics and Statistics Service* (April 1981). According to USDA personnel, this document is still relatively current, and no update has been scheduled.

[b] Joint Chiefs of Staff, Joint Analysis Directorate, "Memorandum for Agencies and Organizations Involved in Wargaming and Military Simulation Modeling," re "Catalog of Wargaming and Military Simulation Models," June 1, 1984.

[c] U.S. Department of Energy, Energy Information Administration, *Directory of Energy Information Administration Model Abstracts,* February 1, 1985.

public documentation is only an abstract of more extensive information available from knowledgeable EIA personnel.

The agencies that use computer models to support major public information products (e.g., statistical reports on forecasts) generally have established means to make modeling information available. Other agencies have not explicitly dealt with the access question. Some simply recite the Freedom of Information Act. Others suggest that information would be made available if requested. There may not be a real issue here, except to the extent that modeling and decision support information is considered classified (primarily with respect to military applications) or subject to executive privilege. Public access to models developed by government contractors can also be a problem. The public availability of such information appears to need clarification. Also, the current central access mechanisms (e.g., the National Technical Information Service and the National Energy Software Center) could be reviewed for adequacy and possible modification.

### Further Research on the Development and Use of Computer Modeling and Decision Support

Judging from the apparent extensive use of computer models and the positive tone of agency comments, computer models and decision support have a significant impact on agency decision making. For example, the Antitrust Division of the Department of Justice, and in particular the Economic Policy Office, stated that "the data manipulation and sophisticated economic and statistical analyses now used in connection with almost all matters could not be performed without computers. While it is impossible to estimate savings in staff time by using computer support, such savings are clearly large." Nonetheless, the results of the OTA survey suggest that the actual use of models for decision making has received little systematic study by federal agencies. Very few (about 4 percent) of the agencies using computer models report having conducted or sponsored such studies. About 7 percent of agencies using decision support report having conducted or sponsored studies.

Of the few agencies that were able to provide concrete examples of studies, only the Federal Emergency Management Agency (FEMA) documented a clearly relevant study program (being carried out both in-house and with NBS assistance). It is likely that some study programs also exist in other agencies, especially in DOD components, but that the details or even the existence of such studies are unknown to headquarters personnel. The responses of the army, navy, and air force headquarters noted the decentralized nature of agency operations, which makes it difficult, absent a major data collection effort, to be fully knowledgeable about prior or ongoing studies. On the other hand, neither the JCS nor the Program Analysis and Evaluation Office (in the Office of the Secretary of Defense) indicated any

such studies, although these two components make heavy use of computer models. It is possible that such studies may be classified, although no indication to this effect was made to OTA by knowledgeable DOD personnel. JCS staff state that no such studies are conducted because the substantial value of computer modeling is clear and undisputed and, in any event, evaluation studies would be difficult to do, given the multiple factors that affect JCS decisions. Computer model results are just one input among many.

On the other hand, FEMA has made a major commitment to evaluate its computer models, many of which are intended to support planning for, and decision making under, emergency conditions. For example, in 1982, FEMA prepared a 130-page report of the FEMA Modeling Task Force that outlined a comprehensive plan for review and evaluation of FEMA modeling and analytical activities.[15] In 1984, reports were issued on various FEMA models, including the dynamic general equilibrium model designed to simulate economic conditions before and after an emergency, including nuclear attack, general wartime mobilization, and other severe economic disruptions,[16] and the damage assessment model designed to estimate the effects of a nuclear attack on various critical resources such as livestock, crops, housing, hospitals, and physicians.[17]

These and other models are then to be evaluated within a framework developed by the Center for Applied Mathematics of NBS under contract to FEMA. The evaluation procedure is intended to, among other things, test the extent to which a model meets user requirements. NBS has identified a wide range of analytical techniques for model evaluation:[18]

- Descriptive analysis (e.g., motivation of model, theoretical underpinnings, model development).
- Program verification and analysis (e.g., review of documentation and source code, model implementation).
- Data audit (e.g., review of documentation, analysis of computerized files).
- Sensitivity analysis (e.g., error analysis, statistical analysis, model stability).
- Program usability (e.g., user-model interface, maintenance and update procedures).

This NBS effort for FEMA represents a continuation of and builds on earlier work conducted in part for EIA and could very well serve as a prototype for other agencies.

Beyond this, there is a considerable body of research and discussion in the published academic and scholarly literature,[19] popular and trade press, and various research reports, for example, those sponsored by NSF on the use of models and decision analysis in risk assessment.[20] Also, variants of com-

puter modeling and decision analysis are being used in the development of computer-based expert systems and artificial intelligence.

In sum, however, although many agencies believe in the utility of computer modeling and decision analytic techniques, few apparently think that studies are worth the time and resources. Nonetheless, it seems highly unlikely that all agencies are making the best and most cost-effective use of such techniques. A coordinated, modest research program could help illuminate the kinds of techniques and applications that are working well and those that are not. The results of such research would presumably facilitate the exchange of knowledge about computer modeling and decision support and lead to improved cost-effectiveness. The results would also be helpful to the development of model guidelines.

In addition to encouraging and funding research, other mechanisms for sharing knowledge could be encouraged, such as professional forums for model developers and users (as has been tried in, for example, the energy and water resource modeling areas) and additional training opportunities.

The limited research that is available, primarily academic research on model implementation, suggests that models (and, by extension, other decision analytic techniques) can and do have a significant impact on agency decision making. Models may become a significant element in the process of negotiation over assumptions and options that is an integral part of agency (and, in general, political) decision making. However, models can be misused and abused. It may be important to understand the models and their roles in order to understand the ultimate decision.[21]

From this perspective, then, the results of further research may provide some new insights as to what kinds of questions should be asked and information requested in conducting oversight on agency decisions and what kinds of techniques might be useful in program evaluations and audits conducted by GAO and others. GAO and agency program evaluation and audit offices are generally very active and look for ways to improve evaluation and audit methodologies. Indeed, GAO is required, by the Congressional Budget Act of 1974, to monitor and recommend improvements in program and budget information for congressional use. GAO has identified needed improvements in DOD's planning, programming, and budgeting system, in the Environmental Protection Agency's cost-benefit analyses of environmental regulations, and in DOD's procedures for estimating weapons system costs.[22] In all these areas, decision analytic techniques have a potential role, especially techniques that combine quantitative and qualitative information, identify ranges of uncertainty, and specify the nature and extent of subjective value judgments to the extent present in the analysis. GAO and other audit agencies could experiment with such decision analytic techniques to ascertain their potential to improve program and budget information for congressional use.

### Further Testing and Development of the Decision Conference Technique

Despite the widespread and frequently sophisticated use of computer-based decision support by federal agencies, the results of this effort appear to be used largely by agency staff or, at the most, presented to agency decision makers for consideration along with other inputs. There appear to be relatively few situations in which the decision makers themselves actively participate in the decision analytic process. OTA located only one agency that has a formal program to do this: the decision conference facility of the Office of Program Planning and Evaluation in the Department of Commerce (DOC).

This DOC decision conference facility is used to bring key staff and decision makers together for, typically, one or two days to work through a decision problem using appropriate computer and analytical tools. Decision conference staff do advance work prior to the conference and serve as facilitators, analytical experts, and rapporteurs during the conference. But the primary participants are the decision maker(s) and his or her staff. The DOC decision conferences use a wide range of computer-assisted analytical techniques, including spreadsheet software, quantitative, and qualitative judgmental, depending on what is most useful.[23] A list of illustrative decision conferences is shown in Table 11.4.

OTA found that DOD does not appear to have such a facility, despite DOD's extensive use of computer-based decision analytic techniques. DOD does have numerous decision analytic support centers throughout the various service branches and commands, but they are at the staff and research levels. For example, the JCS staff conducts extensive studies (in-house and by contract) using modeling and decision analytic techniques, but the Joint Chiefs themselves do not normally participate, except to the extent of approving the major studies. The results of selected decision analytic studies are presented to the Joint Chiefs when relevant to a decision problem at hand.

The decision conference appears to have substantial potential, but the general consensus among practitioners is that further development and testing are needed prior to widespread application. Moreover, few decision makers are even aware of the technique, and even fewer have tried it.

One of the keys to a successful decision conference is the direct and full participation of the decision makers. In order to have greater use of the technique, decision makers need both greater awareness and greater understanding of the technique. Conducting pilot tests in selected programmatic areas, holding a workshop or conference, and commissioning a special report on the subject are actions that could help improve awareness and understanding.

One of the areas thought to be most suited for the decision conference approach is R&D decision making. The National Marine Fisheries Service

**Table 11.4**
**Illustrative Decision Conferences Conducted by the Office of Program Planning and Evaluation, U.S. Department of Commerce, 1984–1985**

1. Development of Program and Budget Priorities for the U.S. National Marine Fisheries Service: (a) FY 1986; (b) FY 1987.
2. Promotion of Tourism to the United States—An Assessment of Alternative Marketing Strategies Available to the Department of Commerce in Six Regional Foreign Markets.
3. Review of Alternative Programs and Service Delivery Strategies for the Minority Business Development Agency.
4. Allocation of Saltonstall/Kennedy Fisheries Development Grant Program Funds—Priority Setting for Grant Applications.
5. Assessment of Alternative Foreign Trade Strategies for Promoting the Export of Auto Parts to Japan.
6. Development and Evaluation of Alternative Staffing Standards for Selected, Governmentwide Administrative Functions (President's Council on Management Improvements): (a) Personnel; (b) Procurement; (c) Warehousing.
7. Assessment of Alternative Long-Term Goals, Strategies and Implementation Mechanisms for the Telecommunications, Computer, and Information Programs of the Department of Commerce.
8. Assessment of Alternative Long-Term Strategies for Promoting Technological Innovation and the Transfer of Technology from Federal Laboratories to the Private Sector (Preliminary).
9. Assessment of Alternative Operating Objectives and Resource Allocations for Selected Administrative Activities of the Department of Commerce: a) Personnel and Civil Rights Functions; b) Management and Information Systems Development; c) Financial Assistant Oversight Activities; and d) Regional Administrative Support Operations.
10. Alternative Programmatic Allocation of Field Personnel Resources, Center for Food Safety and Applied Nutrition of the U.S. Food and Drug Administration.

*Source:* Office of Program Planning and Evaluation/Department of Commerce.

(NMFS) (DOC) used a decision conference for decisions on the R&D budget for fiscal years 1986 and 1987. However, it should be noted that NMFS had been exploring decision analysis for several years, and thus appears to have been favorably predisposed.[24] Decision analytic studies also have been used as significant input to R&D decisions at DOC although not in the decision conference format adopted at DOC. At DOC, decision conferences have been conducted on budget, programmatic, and strategic decisions.

The real power of the decision conference technique (or concept) is its potential to bring the full range of computer tools, models, analytical techniques, and the like into focus for the decision maker within a framework that is relevant to the decision maker. This is a concept that has been visualized and partially developed over the past twenty years or so by numerous researchers and innovators.[25] Table 11.5 places the decision conference in the context of other computer-supported conference room concepts. Different decision conference configurations are possible. For example, DOC uses software from the electronic boardroom and information center concepts in

**Table 11.5**
**Comparison of Computer-Supported Conference Room Concepts**

***Electronic boardroom:***
Computer and audiovisuals

***Teleconferencing facility:***
Computer and communications

***Information center:***
Computer, databases, and software tools

***Decision conference:***
Computer and models

| Element | Electronic boardroom | Teleconference facility | Information center | Decision conference |
|---|---|---|---|---|
| Hardware.... | Conference room; audiovisuals; graphic displays; computer | Conference room; audiovisuals; audio, computer, or video telecommunication controller | Conference room; large-screen video projector; computer; display terminals | Conference room; large-screen video projector; display terminals; voting terminals |
| Software .... | Interactive graphics | Communications | Database management software; statistical packages; retrieval, graphics, and text processing software | Decision analysis software; modeling software; voting tally and display software |
| Orgware..... | Audiovisuals; corporate reports; standard meeting protocols | Audiovisuals; teleconference protocols | Corporate and other databases; standard meeting protocols; standard meetings (e.g., annual report, market forecast) | Democratic decisionmaking protocols (e.g., one person one vote; all major interests represented; majority opinion rules) |
| People ...... | Participants; audiovisual technician | Participants (in two or more locations); teleconference facilitator | Participants; computer specialists; modeling specialists | Participants; decision analysts; group process facilitators |
| Examples ... | Not available. Custom-tailored for each site although some "modular" audiovisual rooms exist | Picturephone Meeting Service; Participate | HOBO System; SYSTEM W; EIS, Express, XSIM | Group Decision Aid; Decision Conferences of DDI and SUNY, Albany |

*Source:* Kenneth L. Kraemer and John L. King, "Computer-Supported Conference Rooms: Final Report of a State of the Art Study" (December 1983), pp. 8, 10.

addition to the software listed under decision conference, and it uses the orgware (i.e., organizational data and procedures) from the electronic boardroom and information center instead of the orgware listed under decision conference.

Overall, the decision conference concept is quite flexible, and many of the elements of the various concepts shown in Table 11.5 are interchangeable. Thus, it is feasible for a computer- or video-conferencing capability, for example, to be added to the decision conference. Indeed, OTA's survey revealed that some agencies are already using computer conferencing, although not as part of decision conferences. For example, the U.S. Geological Survey makes extensive use of computer-conferencing on such diverse topics as cartography, geoscience, computer hardware and software problems, news releases, and Mount Saint Helens' volcanic activity bulletins.

Another variation on the decision conference concept, interactive management, is intended to deal with three principal functions of managers: intelligence (finding and clarifying problems), design (generating or conceptualizing new or improved alternative solutions), and choice (selecting the preferred solution).[26] Like other decision conference concepts, the interactive management approach utilizes a situation room with appropriate audiovisual and computer support. What distinguishes interactive management is the explicit focus on intelligence, design, and choice and the use of a specific set of methodologies to structure ideas, design alternatives, and analyze trade-offs.[27] Several federal agencies have utilized the interactive management decision approach, including the Forest Service and Agricultural Research Service (Department of Agriculture), National Marine Fisheries Service (DOC), and Food and Drug Administration (Department of Health and Human Services).[28]

In sum, Kraemer and King's 1983 prognosis that computer-supported conference techniques are "likely to grow at a slow pace over the next 2 years, and pick up a bit thereafter"[29] may be coming true. It is now well over two years later, and the decision conference technique (sometimes also known under the rubric of group decision support systems or strategic planning decision systems) is now considered to be at the cutting edge of computer-based decision analysis.[30]

## NOTES

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1. See Saul I. Gass and Roger L. Sisson, *A Guide to Models in Governmental Planning and Operations,* report by Mathematica, Inc., prepared for U.S. Environ-

mental Protection Agency (August 1974); U.S. Congress, Office of Technology Assessment, *Information Technology R&D: Critical Trends and Issues,* OTA-CIT-268 (Washington, D.C.: U.S. Government Printing Office, February 1985).

2. The original numerical weather forecast models were run on first-generation mainframe computers (e.g., IBM 701) in the 1950s, and the original atmospheric general circulation models on second-generation computers (e.g., IBM 7094) in the 1960s. The first global coupled atmosphere-ocean model was run in the mid-1970s on the state-of-the-art third-generation computers (e.g., IBM 360-195). Today, the most complex climate models are straining the capability of current supercomputers (e.g., Cray-2) and are providing the impetus for climate modelers to move up to even more powerful supercomputers.

3. Stephen E. Frantzich, "Congressional Applications of Information Technology," OTA contractor report prepared by Congressional Data Associates (February 1985).

4. Robert Miewald, Keith Mueller, and Robert Sittig, "State Legislature Use of Information Technology in Oversight," OTA contractor report prepared by the University of Nebraska-Lincoln (January 1985).

5. U.S. General Accounting Office, *Survey to Identify Models Used by Executive Agencies in the Policymaking Process,* GAO/PAD-82-46 (September 24, 1982).

6. Howard Raiffa, *Decision Analysis* (Reading, MA: Addison-Wesley, 1968). Also see Rex V. Brown, "A Brief Review of Executive Agency Uses of Personalized Decision Analysis and Support," OTA contractor report prepared by Decision Science Consortium (March 1985).

7. U.S. General Accounting Office, *Ways to Improve Management of Federally Funded Computerized Models* (August 23, 1976); *Models and Their Role in GAO* (October 1978); *Guidelines for Model Evaluation* (January 1979); U.S. Department of Commerce, National Bureau of Standards, *Utility and Use of Large-Scale Mathematical Models,* ed. Saul I. Gass (October 1981).

8. See, for example, Brian Wynne, "The Institutional Context of Science, Models, and Policy: The IIASA Energy Study," *Policy Sciences* 17, no. 3 (November 1984): 277–320; W. Hafele and H. H. Rogner, "A Technical Appraisal of the IIASA Energy Scenarios? A Rebuttal," *Policy Sciences* 17, no. 4 (December 1984): 341–365; Bill Keepin and Brian Wynne, "Technical Analysis of IIASA Energy Scenarios," *Nature* 312 (December 1984): 691–695; and David Dickson, "Global Energy Study Under Fire," *Science* 227 (January 1985): 4. For a discussion of errors in forecasting models, see William Ascher, *Forecasting: An Appraisal for Policymakers and Planners* (Baltimore, MD: Johns Hopkins University Press, 1978).

9. See, for example, GAO, *Guidelines;* NBS, *Utility;* Richard Richels, "Building Good Models Is Not Enough," *Interfaces* 11, no. 4 (August 1981): 48–51; and Saul I. Gass and Lambert S. Joel, "Concepts of Model Confidence," *Computers and Operations Research* 8, no. 4 (1981): 341–346.

10. U.S. Congress, Office of Technology Assessment, *Use of Models for Water Resources Management, Planning, and Policy* (Washington, D.C.: U.S. Government Printing Office, August 1982).

11. Public Law 93-275, sec. 57(B)(1) as amended by Public Law 94-385.

12. See Energy Information Administration Order No. E15910.3A, "Guidelines and Procedures for Model and Analysis Documentation," October 1, 1982, and Or-

der No. E15910.4A, "Guidelines and Procedures for the Preparation of Model Archival Packages," February 23, 1982.

13. See Energy Information Administration, *Directory of Energy Information Administration Model Abstracts* (February 1, 1985); and Professional Audit Review Team, *Performance Evaluation of the Energy Information Administration,* report to the President and Congress (June 15, 1984), which noted significant progress on model documentation but with additional work still needed.

14. Karen Liu and Vernon O. Roninger, *The World Grain-Oil-Seeds-Livestock (GOL) Model, A Simplified Version,* ERS Staff Report No. AGE5850128, U.S. Department of Agriculture, Economic Research Service, International Economics Division (February 1985).

15. Bruce J. Campbell, Task Force Chairman, "FEMA Modeling Task Force Study," FEMA (May 1982).

16. Richard J. Goettle III and Edward A. Hudson, *Final Report on the Dynamic General Equilibrium Model,* prepared for FEMA under contract FPA 76-9 (February 1984).

17. FEMA, *Ready II Damage Estimation System Advanced Analytical Programs,* TM-308 (February 1984).

18. Robert E. Chapman, Robert G. Hendrickson, Saul I. Gass, and James J. Filliben, *Analytical Techniques for Evaluating Emergency Management Models and Data Bases,* prepared by NBS Center for Applied Mathematics under contract to FEMA (May 1985).

19. For further discussion of the history and techniques of decision analysis, see, for example, R. V. Brown, A. S. Kahr, and C. Peterson, *Decision Analysis for the Manager* (New York: Holt, Rinehart & Winston, 1974); S. Barclay, R. V. Brown, C. W. Kelley, C. R. Peterson, L. D. Philips, and J. Selvidge, *Handbook for Decision Analysis* (McLean, VA: Decisions & Designs, September 1977). Also see Rex V. Brown and Jacob W. Ulvila, "Selected Applications of Computer-Aided Decision Analysis and Support," OTA contractor report prepared by Decision Science Consortium (May 1985).

20. See, for example, Judith D. Bentkover et al., *Benefits Assessment: The State-of-the-Art,* prepared by Arthur D. Little, Inc. for the National Science Foundation (December 1984); and Miley W. Merkhofer et al., *Risk Assessment and Risk Assessment Methods: The State-of-the-Art,* prepared by Charles River Associates and Applied Decision Analysis for the National Science Foundation (December 1984).

21. See, for example, Kenneth L. Kraemer, "The Politics of Model Implementation," *Systems, Objectives, Solutions* 1 (1981): 161–178; John Leslie King, "Successful Implementation of Large-Scale Decision Support Systems: Computerized Models in U.S. Economic Policy Making," *Systems, Objectives, Solutions* 3 (1983): 183–205; John Leslie King, "Ideology and Use of Large-Scale Decision Support Systems in National Policymaking," *Systems, Objectives, and Solutions* 4 (1984); William H. Dutton and Kenneth L. Kraemer, *Modeling as Negotiating: The Political Dynamics of Computer Models in the Policy Process* (Norwood, NJ: Ablex, 1985); and Lance N. Antrim, "Computer Models as an Aid to Negotiation: The Experience in the Law of the Sea Conference" (November 1984).

22. See U.S. General Accounting Office, *Progress in Improving Program and Budget Information for Congressional Use,* GAO/PAD-82-47 (September 1, 1982);

GAO, *The DOD Planning, Programming, and Budgeting System,* GAO/OACG-84-5 (September 1983); GAO, *Cost-Benefit Analysis Can Be Useful in Assessing Environmental Regulations, Despite Limitations,* GAO-RCED-84-62 (April 6, 1984); GAO, "OD Needs to Provide More Credible Weapon Systems Cost Estimates to Congress," GAO/NSIAD-84-70 (May 24, 1984).

23. For more detailed discussion, see Charles Treat, "Commerce Computer Center Attracts Attention," *Commerce People* 6, no. 4 (April 1985): 5; Charles F. Treat, "Modeling and Decision Analysis for Management" (paper prepared for the Government Computer Expo, June 13, 1985); and William A. Maldens, "Better Data Doesn't Always Mean Better Decisions—Decision Analysis Does," *Government Executive* (November–December 1984): 10, 14.

24. See Bruce Norman, "What Policy Analysis Can Do for You—A Survey," NMFS memo to Winfred H. Meibohm, October 13, 1978; and Hoyt A. Wheeland, "NMFS Decision Analysis," NMFS memo to William H. Stevenson, June 16, 1982.

25. Among the many researchers, the following are illustrative (in alphabetical order): Rex Brown, Dennis Buede, William Dutton, Kenneth Kraemer, John King, Starr Roxanne Hiltz, Lee Merkhofer, Thomas Sheridan, and Murray Turoff. For a good review and extensive references, see Kenneth L. Kraemer and John L. King, "Computer Supported Conference Rooms: Final Report of a State of the Art Study" (December 1983), presented as a paper under the title "Computer-Based Systems for Group Decision Support," Academy of Management Annual Conference, August 15, 1984.

26. Alexander N. Christakis and David B. Keever, "An Overview of Interactive Management" (Fairfax, VA: Center for Interactive Management, George Mason University, 1984).

27. Ibid.

28. See *CIM News* (Fall 1985).

29. Kraemer and King, "Conference Rooms," p. 7.

30. At the November 1985 meeting of ORSA/TIM, experts such as Warren Walker, Rand Corp.; Paul Gray, Clarement Graduate School; George Huber, University of Texas at Austin; and Shao-ju Lee, California State University at Northridge agreed on the need to develop and implement a group decision support systems concept as the state of the art in decision support systems. Also see Bernard C. Reimann, "Decision Support Systems: Strategic Management Tools for the Eighties," *Business Horizons* (September–October 1985): 71–77. Also see Fred B. Wood, "Prospects for General Systems Decision Support Centers in the Federal Government" (paper prepared for the Annual Meeting of the Society for General Systems Research, Philadelphia, May 1986), published in *Project Appraisal* 2, no. 2 (June 1987): 97–101.

# Bibliography

## BOOKS AND JOURNALS


Adair, J. *The Human Subject: The Social Psychology of the Psychological Experiment*. Boston: Little, Brown, 1973.

Alter, S. L. *Decision Support Systems—Current Practice and Continuing Challenges*. Reading, MA: Addison-Wesley, 1980.

Andriole, S. J. (ed.). *Microcomputer Decision Support Systems: Design, Implementation and Evaluation*. Amsterdam: North-Holland, 1986.

Arden, B. W. *What Can Be Automated? The Computer Science and Engineering Research Study*. Cambridge, MA: MIT Press, 1980.

Arkes, H. R., and K. R. Hammond (eds.). *Judgment and Decision Making*. Cambridge: Cambridge University Press, 1986.

Ascher, W. *Forecasting: An Appraisal for Policymakers and Planners*. Baltimore, MD: Johns Hopkins University Press, 1978.

Axelrod, P. (ed.). *Structure of Decision: The Cognitive Maps of Political Elites*. Princeton, NJ: Princeton University Press, 1976.

Barclay, R. V., et al. *Handbook for Decision Analysis*. McLean, VA: Decision & Designs, September 1977.

Bell, D. E., et al. (eds.). *Decision-Making: Descriptive, Normative and Prescriptive Interactions*. Cambridge: Cambridge University Press, 1989.

Bentkover, J. D., et al. *Benefits Assessment: The State-of-the-Art*. Prepared by Arthur D. Little, Inc. for the National Science Foundation, December 1984.

Bergerson, P., and B. Nedwek (eds.). *Proceedings of the Eighth National Conference on Teaching Public Administration*, 1985.

Brehmer, B., et al. *New Directions on Research on Decision Making*. Amsterdam: North-Holland, 1986.

Brown, R. V. *A Brief Review of Executive Agency Uses of Personalized Decision Analysis and Support*. OTA contractor report prepared by Decision Science Consortium, March 1985.

Brown, R. V., and J. W. Ulvila. *Selected Applications of Computer-Aided Decision Analysis and Support.* OTA contractor report prepared by Decision Science Consortium, March, 1985.

Brown, R. V. et al. *Decision Analysis for the Manager.* New York: Holt, Rinehart & Winston, 1974.

Bunge, M. *Scientific Research.* Berlin: Springer, 1967.

Bunn, D. W. *Applied Decision Analysis.* New York: McGraw-Hill, 1984.

Carroll, T. O. *Decision Power with Supersheets.* Homewood, IL: Dow Jones-Irwin, 1986.

———. *Modeling Tomorrow's Energy System—Applications of Linear Programming.* Lexington, MA: COMAP, 1986.

Chankong, V., and Y. Y. Haimes. *Multiobjective Decision Making: Theory and Methodology.* Amsterdam: North-Holland, 1983.

Chapman, R. E., et al. *Analytical Techniques for Evaluating Emergency Management Models and Data Bases.* Prepared by NBS Center for Applied Mathematics under contract to FEMA, May 1985.

Checkland, P. *Systems Thinking, Systems Practice.* Chichester, NY: Wiley, 1981.

Cook, T., and D. Campbell. *Quasi-Experimentation: Design and Analysis Issues for Field Settings.* Chicago: Rand McNally, 1979.

Covello, V., et al. (eds.). *Technology Assessment, Environmental Impact Assessment and Risk Analysis.* Berlin: Springer Verlag, 1983.

Cronbach, L. *Designing Evaluations of Educational and Social Programs.* San Francisco: Jossey-Bass, 1982.

Davis, G. B., and M. H. Olson. *Management Information Systems.* New York: McGraw-Hill, 1985.

de Groot, A. D. *Thought and Choice in Chess.* The Hague: Mouton, 1965.

Decision Analysis Unit (ed.). *MAUD6 User Manual.* London: London School of Economics and Political Science, 1986.

Delbecq, A., et al. *Group Techniques for Program Planning.* Glenview, IL: Scott Foresman, 1975.

Despontin, M., et al. (eds.). *Macro Economic Planning with Conflicting Goals.* Berlin: Springer, 1984.

Douglas, M., and Aaron Wildavsky. *Risk and Culture.* Beverly Hills, CA: Sage, 1982.

Dutton, W. H., and K. L. Kraemer. *Modeling as Negotiating: The Political Dynamics of Computer Models in the Policy Process.* Norwood, NJ: Ablex, 1985.

Eden, C. S. Jones, and C. Sims. *Thinking in Organizations.* London: Macmillan, 1980.

Energy Information Administration. *Directory of Energy Information Administration Model Abstracts.* February 1, 1985.

Evers-Kiebooms, G., et al. *Genetic Risk, Risk Perception, and Decision Making.* New York: LISS, 1987.

Federal Emergency Management Agency. *Ready II Damage Estimation System Advanced Analytical Programs.* TM-308. February 1984.

Festinger, L. *Conflict, Decision and Dissonance.* Stanford: Stanford University Press, 1964.

Fishburg, P. C. *Utility Theory for Decision Making.* New York: Wiley, 1970.

Frantzich, S. E. *Congressional Applications of Information Technology.* OTA contractor report prepared by Congressional Data Associates. February 1985.
French, S. *Decision Theory.* West Sussex, UK: Ellis Horwood Limited, 1986.
French, S., et al. (eds.). *Multi-Objective Decision Making.* London: Academic Press, 1983.
Freudenberg, W., and E. Rosa (eds.). *Public Reaction to Nuclear Power.* Boulder, CO: Westview Press, 1984.
Frey, D., et al. (eds.). *Angewandte Psychologie—ein Lehrbuch.* Munich: Psychologie-Verlags-Union.
Gass, S. I. (ed). *Utility and Use of Large-Scale Mathematical Models.* U.S. Department of Commerce, National Bureau of Standards, October 1981.
Gass, Saul, et al. (eds.). *Impacts of Microcomputers on Operations Research.* Amsterdam: North-Holland, 1986.
Gass, S. I., and R. L. Sisson. *A Guide to Models in Governmental Planning and Operations.* Report by Mathematica, prepared for U.S. Environmental Protection Agency. August 1974.
Gilbert, T. *Human Competence.* New York: McGraw-Hill, 1978.
Ginzberg, M. J. et al. (eds.). *Decision Support Systems.* Amsterdam: North-Holland, 1982.
Glantz, J. et al. "Determining an Appropriate Smoking Policy for the Workplace." Unpublished report. School of Government and Business Administration, George Washington University, 1986.
Goettle, R. J. III, and E. A. Hudson. *Final Report on the Dynamic General Equilibrium Model.* Prepared for FEMA under contract FPA 76-9. February 1984.
Greenblat, C. S., and R. D. Duke. *Principles and Practices of Gaming-Simulation.* Beverly Hills: Sage Publications, 1981.
Greif, I. (ed.). *Computer-Supported Cooperative Work: A Book of Readings.* San Mateo, CA: Morgan Kaufmann, 1988.
Hammond, K. R. et al. (eds.). *Human Judgment and Decision Making: Theories, Methods and Procedures.* New York: Praeger Publishers, 1980.
Hamza, M. H. (ed.). *Proceedings of IASTED International Conference "Expert Systems."* Geneva: Acta Press, 1987.
Hayes-Roth, F., et al. *Building Expert Systems.* Reading, MA: Addison-Wesley, 1983.
Herman, J., et al. *Evaluator's Handbook.* London: Sage, 1988.
Herwijnen, M., and R. Janssen. *Beslissings Ondersteunend Systeem voor Discrete Alternatieven (BOSDA).* Amsterdam: Functioneel ontwerp, Instituut voor Milieuvraagstukken, Brije Universiteit, 1987.
Hickling, A. *Managing Decisions: The Strategic Choice Approach.* Rugby: Mantec Publications, 1974.
Hoffman, P. J. *Quasi-AI in the Development of Expert Systems.* Los Altos, CA: Magic7 Software Co., 1986.
Hogarth, R. M., and R. W. Reder (eds.). *Rational Choice.* Chicago: University of Chicago Press, 1987.
Holtzman, S. *Intelligent Decision Systems.* Reading, MA: Addison-Wesley, 1989.
Humphreys, C. P., and D. A. Wisudha. *Methods and Tools for Structuring and Analysing Decision Problems.* Technical report 87-1. London: Decision Analysis Unit, London School of Economics and Political Sciences, 1987.

Humphreys, P., A. Oldfield, and J. Allan. *Intuitive Handling of Decision Problems: A Five-Level Empirical Analysis.* London: Decision Analysis Unit, London School of Economics, 1987.

Humphreys, P., et al. *Analysing and Aiding Decision Processes.* Amsterdam: North-Holland, 1983.

Humphreys, P. et al. (eds.). *Analyzing and Aiding Decision Processes.* Amsterdam: North-Holland, 1983.

Humphreys, P., D. Svenson, and A. Vari (eds.). *Analyzing and Aiding Decision Processes.* Amsterdam: North-Holland, 1983.

Humphreys, P., and A. Wisudha. *Multi-Attribute Utility Decomposition MAUD.* London: Brunel University, 1979.

Irle, M. (ed.). *Studies in Decision Making: Social Psychological and Socio-Economic Analysis.* Berlin/New York: Walter de Gruyter, 1982.

Janis, I. *Groupthink.* Boston: Houghton Mifflin, 1981.

Janis, I., and L. Mann. *Decision Making: A Psychological Analysis of Conflict, Choice and Commitment.* New York: Free Press, 1979.

———. *Decision Making.* New York: Free Press, 1977.

Joint Chiefs of Staff. Memorandum for Agencies and Organizations Involved in Wargaming and Military Simulation Modeling. Joint Analysis Directorate, re. Catalog of Wargaming and Military Simulation Models, June 1, 1984.

Kahneman, D., et al. (eds.). *Judgment under Uncertainty: Heuristics and Biases.* Cambridge: Cambridge University Press, 1982.

Kaplan, M., and S. Schwartz (eds.). *Human Judgment and Decision Processes.* New York: Academic Press, 1977.

Karlsson, G. *A Phenomenological Psychological Study of the Experience of Making a Decision: Theoretical Foundation and Empirical Applications in the Field of Decision-Making and Choice.* Stockholm: Akadmitryck, 1987.

Keen, P., and M. Scott-Morton. *Decision Support Systems: An Organizational Perspective.* Reading, MA: Addison-Wesley, 1978.

Keeney, R., and H. Raiffa. *Decisions with Multiple Objectives: Preferences and Value Tradeoffs.* New York: Wiley, 1976.

Kendall, P., and J. Butcher (eds.). *Handbook of Research Methods in Clinical Psychology.* New York: Wiley, 1982.

Klix, F., and H. Wandke (eds.). *Man-Computer Interaction Research.* Amsterdam: North-Holland.

Lee, R., et al. *Organizational Decision Support Systems.* Amsterdam: North-Holland, 1988.

Lewis, L. F., and K. Keleman. "Experiences with GDSS Development: Lab and Field Studies." Unpublished manuscript.

Lindzey, G., and E. Aronson (eds.). *The Handbook of Social Psychology.* London: Random House, 1985.

Liu, K., and V. O. Roninger. *The World Grain-Oil-Seeds-Livestock (GOL) Model, A Simplified Version.* ERS Staff Report No. AGE5850128, U.S. Department of Agriculture, Economic Research Service, International Economics Division, February 1985.

McGrew, A. G., and M. J. Wilson (eds.). *Decision Making: Approaches and Analysis.* Manchester: Manchester University Press, 1982.

McLean, E. R., and H. G. Sol (eds.). *Decision Support Systems: A Decade in Perspective.* Amsterdam: North-Holland, 1986.

Merkhofer, M. W., et al. *Risk Assessment and Risk Assessment Methods: The State-of-the-Art.* Prepared by Charles River Associates and Applied Decision Analysis for NSF, December 1984.

Methlie, L., and R. Sprague (eds.). *Knowledge Representation for Decision Support Systems.* Amsterdam: North-Holland, 1985.

———. *Knowledge Representation for Decision Support Systems.* Amsterdam: North-Holland, Proceeding IFIP, 1984.

Michie, D., and I. Bratko. *Expert Systems: Automating Knowledge Acquisition.* Reading, MA: Addison-Wesley, 1986.

Miewald, R., et al. *State Legislature Use of Information Technology in Oversight.* OTA contractor report prepared by the University of Nebraska-Lincoln, January 1985.

Mitra, G. (ed). *Computer Assisted Decision Making.* Amsterdam: Elsevier Science Publishers B.V. (North-Holland), 1986.

Monk, A. *Fundamentals of Human-Computer Interaction.* London: Academic Press, 1984.

Montgomery, H., and D. Svenson (eds.). *Process and Structure in Human Decision Making.* New York: Wiley, 1989.

Moreno, J. *Psychodrama.* New York: Beacon House, 1946.

Nagel, Stuart. *Introducing Decision-Aiding Software.* London: Macmillan, 1989.

Nagel, S., and J. Long. *The P/G% Program Manual.* Urbana, IL: University of Illinois, 1988.

Newell, A., and H. A. Simon. *Human Problem Solving.* Englewood Cliffs, NJ: Prentice-Hall, 1972.

Nijssen, G. M., and T. A. Halpin. *Conceptual Schemas and Relational Databases: A Fact Based Approach.* Englewood Cliffs, NJ; Prentice-Hall, 1989.

Office of Technology Assessment. *Federal Government Information Technology: Management, Security, and Congressional Oversight.* OTA-CIT-297. Washington, DC: U.S. GPO, February 1986.

———. *Information Technology R&D: Critical Trends and Issues.* OTA-CIT-268. Washington, DC: U.S. GPO, February 1986.

———. *Use of Models for Water Resources Management, Planning, and Policy.* Washington, DC: U.S. GPO, August 1982.

Osborn, A. *Applied Imagination.* New York: Scribner's, 1963.

Paradice, D. B. "Databases and Knowledge Bases in Managerial Expert Systems." In *Artificial Intelligence: Implications for Computer Integrated Manufacturing.* Ed. A. Kusiac. Bedford, U.K.: IFS (Publications) Ltd.

Patton, M. *Utilization Focused Evaluation.* London: Sage, 1986.

Paulus, P. B. (ed.). *Psychology of Group Influence.* Hillsdale, NJ: Erlbaum, 1980.

Pelizzari, J. et al. "Analysis of a Bank Acquisition Decision." Unpublished report. School of Government and Business Administration, George Washington University, 1986.

Pitz, G., and J. McKillip. *Decision Analysis for Program Evaluators.* Beverly Hills, CA: Sage, 1984.

Poweke, M.J.D. (ed.). *Nonlinear Optimization 1981.* New York: Academic Press, 1982.

Professional Audit Review Team. *Performance Evaluation of the Energy Information Administration.* Report to the President and Congress, June 15, 1984.

Raiffa, H. *Decision Analysis.* Reading, MA: Addison-Wesley, 1968.

Rajkovič, V., et al. *Evaluation of Microcomputers for Primary and Secondary Schools in Slovenia* (in Slovene language). Zavod SR Slovenije za solstvo, 1985.

Richter, G., et al. *Generic Organizational Frame of Reference*. Brussels: Commission for the European Communities, 1987.

Riedel, S. *Model-Based Evaluation of Decision Aids*. Carbondale: Southern Illinois University, 1986.

Rietveld, P. *Beslissings Ondersteunend Systeem voor Discrete Alternatieven (BOSDA)*. Gevoeligheidsanalyses Bij Multicriteria Beslissingsmethoden. Amsterdam: Instituut voor Milieuvraagstukken, Vrije Universiteit, 1988.

———. *Multiple Objective Decision Methods in Regional Planning*. Amsterdam: North-Holland, 1980.

Rosenthal, R., and R. Rosnow (eds.). *Artifact and Behavioral Research*. New York: Academic Press, 1969.

Rossi, P., and H. Freeman. *Evaluation: A Systematic Approach* (3d ed.). Beverly Hills, CA: Sage, 1985.

Roy, B. *Methodologie multicritére d'aide à la décision*. Paris: Economenica, 1985.

Runreuther, H. (ed). *Risk: A Seminar Series*. Laxenburg, Austria: International Institute for Applied Systems Analysis, 1982.

Russel, S., et al. *Creating Influence Diagrams from Examples*. Berkeley: Berkeley Expert Systems Laboratory, University of California, 1988.

Saaty, T. L. *The Analytical Hierarchy Process*. New York: McGraw-Hill, 1980.

Sage, A. P. *Methodology for Large Scale Systems*. New York: McGraw-Hill, 1977.

Salvendy, G. (ed.). *Human-Computer Interaction*. Amsterdam: North-Holland, 1984.

Sampson, E. E. *Social Psychology and Contemporary Society*. New York: Wiley, 1971.

Saris, W. E., et al. (eds.). *Sociometric Research:* Volume 1: *Data Collection and Scaling*. London: Macmillan, 1968.

Sarris, V., and A. Parducci (eds.). *Perspectives in Psychological Experimentation — Towards the Year 2000*. London: Erlbaum, 1983.

Savage, L. J. *The Foundations of Statistics*. New York: Wiley, 1954.

Schank, R., and R. Abelson. *Scripts, Plans Goals and Understanding*. Hillsdale, NJ: Erlbaum, 1977.

Schotz, R. (ed.). *Decision Making under Uncertainty*. Amsterdam: North-Holland, 1983.

Schutz, H., and H. Jungermann. *Ansatze und Verfahren zur Hilfe bei Personlichen Entscheidungen*. Berlin: Bericht aus dem Institut fur Psychologie der TU, 1988.

Shaw, M. L. *On Becoming a Personal Scientist*. New York: Academic Press, 1979.

Shneiderman, B. *Designing the User Interface. Strategies for Effective Human-Computer Interaction*. Reading: Addison-Wesley, 1987.

Sjoberg, L., et al. *Decision Analysis and Decision Processes*. Lund, Sweden: Doxa, 1983.

———. (eds.). *Human Decision Making*. Lund, Sweden: Doxa, 1983.

Soelberg, P. "A Study of Decision Making: Job Choice." Ph.D. dissertation, Carnegie Institute of Technology and Massachusetts Institute of Technology, 1967.

Sol, H. G. (ed.). *Processes and Tools for Decision Support.* Amsterdam: North-Holland, 1983.

Sonka, S. T. *Computers in Farming.* New York: McGraw-Hill, 1983.

Sprague, R. H., and E. D. Carlson. *Building Effective Decision Support Systems.* Englewood Cliffs, NJ: Prentice-Hall, 1982.

Sprague, R. H., and H. J. Watson (eds.). *Decision Support Systems: Putting Theory into Practice.* Englewood Cliffs, NJ: Prentice-Hall, 1986.

Steiner, J., and R. H. Dorff. *A Theory of Political Decision Modes: Intraparty Decision Making in Switzerland.* Chapel Hill, NC: University of North Carolina Press, 1980.

Svenson, D., and A. Vari (eds.). *Analyzing and Aiding Decision Processes.* Amsterdam: North-Holland, 1983.

Thomson, V. A. *Decision Theory: Pure and Applied.* New York: University of Illinois, General Learning Press, 1971.

Tietz, R. (ed). *Aspiration Levels in Bargaining and Economic Decision Making.* Berlin: Springer Verlag, 1983.

Tuchinsky, P. M. *Man in Competition with the Spruce Budworm.* Boston: Birkhauser Boston, 1981.

Tufte, E. R. *The Visual Display of Quantitative Information.* Cheshire, CT: Graphics Press, 1985.

United Nations. *Simulation Model on Population and Development (Game for Training).* Department of Technical Cooperation for Development, 1987.

U.S. Department of Agriculture. *Agricultural and Other Economic Models of the Economics and Statistics Service.* Washington, DC: USDA, 1981.

U.S. Department of Energy. *Directory of Energy Information Administration Model Abstracts.* Energy Information Administration, February 1, 1985.

U.S. General Accounting Office. *Cost-Benefit Analysis Can Be Useful in Assessing Environmental Regulations, Despite Limitations.* GAO-RCED-84-62. April 6, 1984.

———. *OD Needs to Provide More Credible Weapons Systems Cost Estimates to Congress.* GAO/NSIAD-84-70. May 24, 1984.

———. *Progress in Improving Program and Budget Information for Congressional Use.* GAO/PAD-82-47. September 1, 1982.

———. *Survey to Identify Models Used by Executive Agencies in the Policymaking Process.* GAO/PAD-82-46. September 24, 1982.

———. *The DOD Planning, Programming, and Budgeting System.* GAO/OACG-84-5. September 1983.

———. *Ways to Improve Management of Federally Funded Computerized Models.* August 23, 1976.

Van de Ven, A. *An Applied Experimental Test of Alternative Decision Making Processes.* Kent, OH: Kent State University, 1973.

Vari, A. *Argumatics: A Text Analysis Procedure for Supporting Problem Formulation.* Budapest, Hungary: Mass Communication Research Center, 1987.

Vickens, D., and P. L. Smith (eds.). *Human Information Processing: Measures, Mechanisms and Models.* Amsterdam: North-Holland, in press.

von Winterfeldt, D., and W. Edwards. *Decision Analysis and Behavioral Research.* Cambridge: Cambridge University Press, 1986.

Voogd, J. H. *Multi Criteria Evaluation for Urban and Regional Planning.* London: Pion, 1983.

Wagenaar, W., and G. Keren. *Does the Expert Know?* New York: Plenum, 1988.

Wallsten, T. S. (ed.). *Cognitive Processes in Choice and Decision Behavior.* Hilldale, NJ: Erlbaum, 1980.

Wendt, D., and C.A.J. Vlek (eds.). *Utility, Probability, and Human Decision Making.* Dordrecht: Reidel, 1975.

Wheeler, D. D., and I. L. Janis. *A Practical Guide for Making Decisions.* New York: Free Press, 1980.

Wright, G. *Behavioural Decision Theory.* Beverly Hills: Sage, 1984.

——— (ed.). *Behavioral Decision Making.* New York: Plenum, 1985.

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